New Results from DØ – Life at the Energy Frontier

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IN DEO SPERAMUS

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Outline

- **Introduction**

- **The DØ experiment**

- **(Some of) the big questions**

- **Where we are**

- **Where we are heading**

- **Conclusions**

What is the universe made of?

- **It is often claimed that humans are naturally curious**
  - **Maybe so, but in my experience they often try to answer this kind of question by sitting and talking and coming up with explanations**
    - **Call it philosophy, or call it shooting the breeze**

- **The only <u>reliable</u> way to answer this question is by directly enquiring through experiment**
  - **not necessarily a "natural human activity", but perhaps the greatest human invention**
  - **Something that is not understood, and therefore not particularly liked, by many people**
  - **often tolerated mainly because it is useful**

- **Something to think about, especially when we are trying to explain scientific projects that are not, a priori, useful**
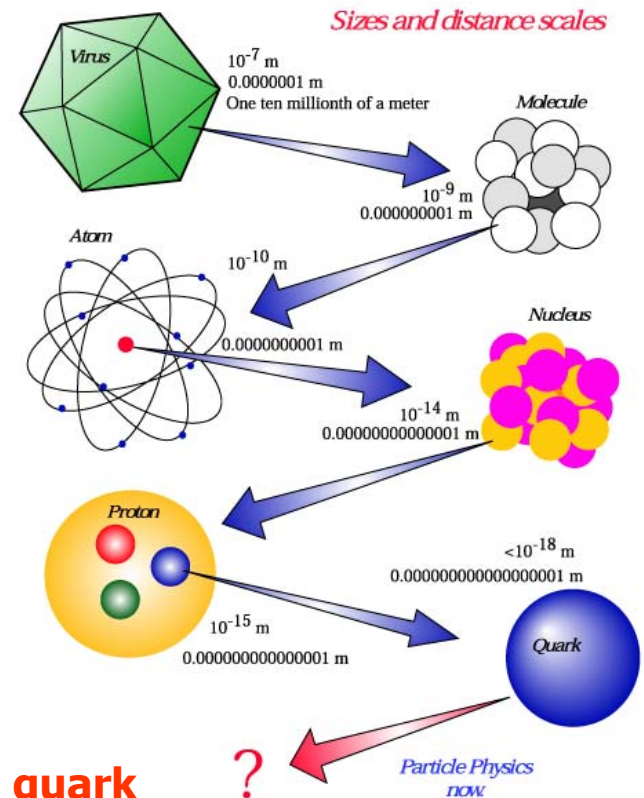
Experiment has taught us:

- **Complex structures in the universe are made by combining simple objects in different ways**
  - **Periodic Table**

- **Apparently diverse phenomena are often different manifestations of the same underlying physics**
  - **Orbits of planets and apples falling from trees**

- **Almost everything is made of small objects that like to stick together**
  - **Particles and Forces**

- **Everyday intuition is not necessarily a good guide**
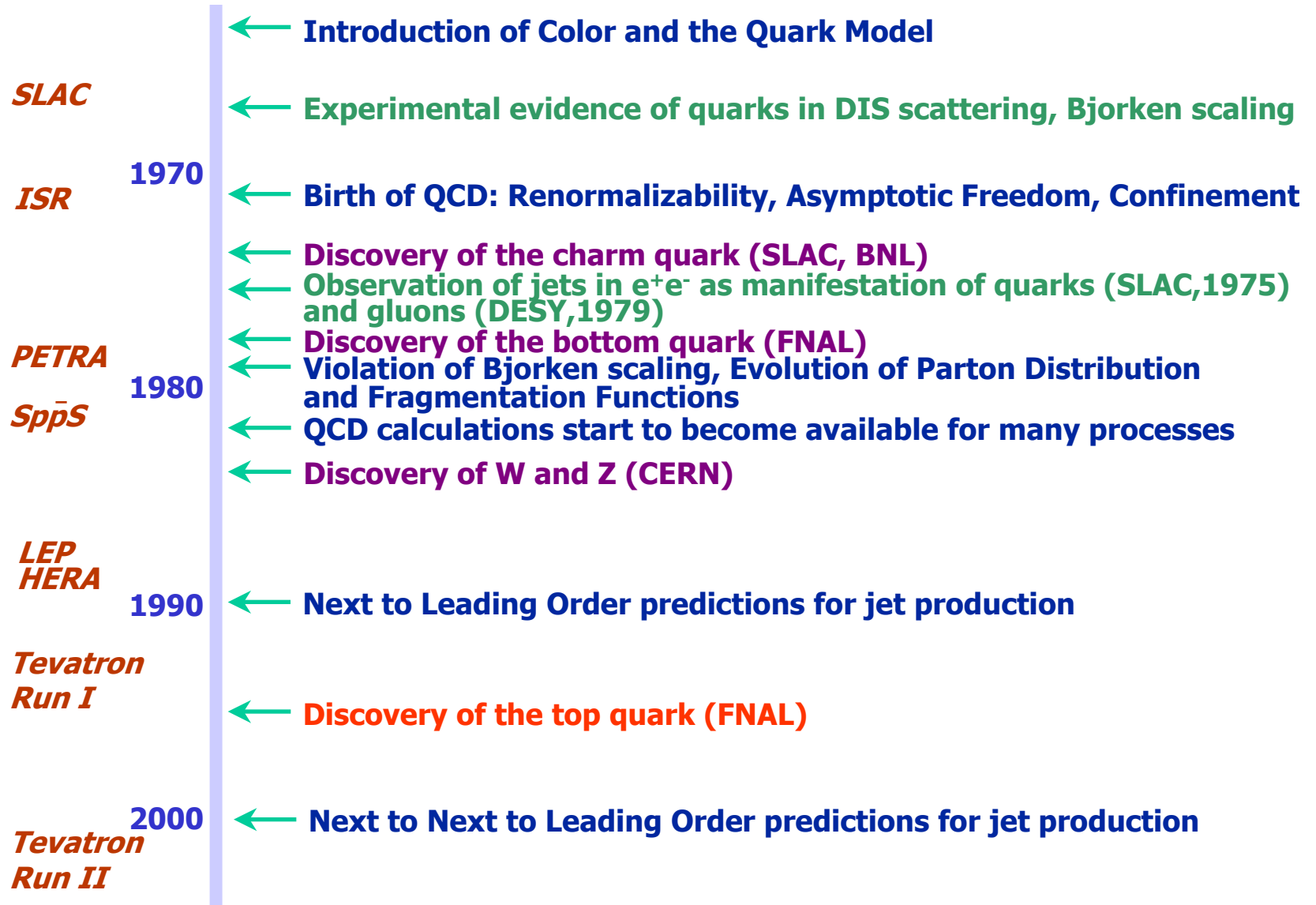 - **We live in a quantum world, even if it's not obvious to us**

Particles and Forces Timeline

- **1897-1920's**
  - **The electron (vacuum tubes)**
  - **Atomic physics, X-rays, quantum mechanics**
- **1930's**
  - **The nucleus (Rutherford's experiment)**
- **1940's**
  - **Nuclear physics**
- **1950's**
  - **Particle physics (mesons & baryons)**
  - **Quantum Field Theory (Feynman et al.)**
- **1960's – 1970's**
  - **Quarks and leptons**
- **1980's**
  - **Electroweak Unification, W and Z bosons**
- **1990's**
  - **Consolidation of the Standard Model, top quark**
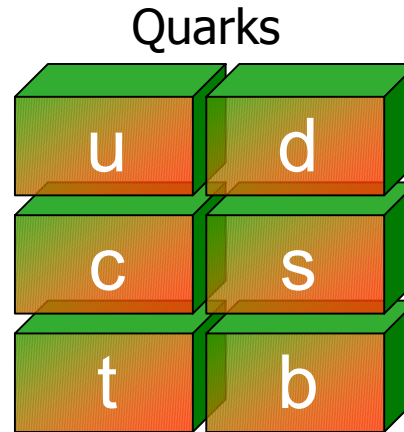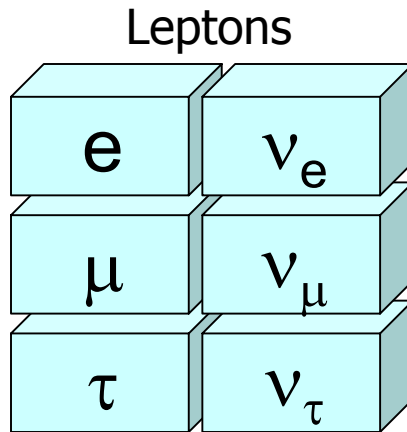 - **Increasing interest in "Quarks to the Cosmos"**

Sizes and distance scales

Virus 10^{-7} m 0.0000001 m One ten millionth of a meter

Molecule 10^{-9} m 0.000000001 m

Atom 10^{-10} m 0.0000000001 m

Nucleus 10^{-14} m 0.00000000000001 m

Proton 10^{-15} m 0.000000000000001 m

Quark $<10^{-18}$ m 0.000000000000000001 m

? Particle Physics now.

HEP (biased) Timeline

← **Introduction of Color and the Quark Model**

SLAC

← **Experimental evidence of quarks in DIS scattering, Bjorken scaling**

1970

ISR

← **Birth of QCD: Renormalizability, Asymptotic Freedom, Confinement**

← **Discovery of the charm quark (SLAC, BNL)**

← **Observation of jets in e^+e^- as manifestation of quarks (SLAC,1975) and gluons (DESY,1979)**

PETRA

← **Discovery of the bottom quark (FNAL)**

← **Violation of Bjorken scaling, Evolution of Parton Distribution and Fragmentation Functions**

1980

SppS̄

← **QCD calculations start to become available for many processes**

← **Discovery of W and Z (CERN)**

LEP
HERA

1990 ← **Next to Leading Order predictions for jet production**

Tevatron Run I

← **Discovery of the top quark (FNAL)**

2000 ← **Next to Next to Leading Order predictions for jet production**

Tevatron Run II

"Standard Model" of Particles and Forces

- **Point like, spin-½ fermionic constituents**

Leptons

e	ν_e
μ	ν_μ
τ	ν_τ

Quarks

u	d
c	s
t	b

- **Which interact by exchanging spin-1 vector bosons**

Electromagnetic	10^{-2}
Strong	1
Weak	10^{-6}
Gravity	10^{-40}

γ

g

W⁺ Z⁰ W⁻
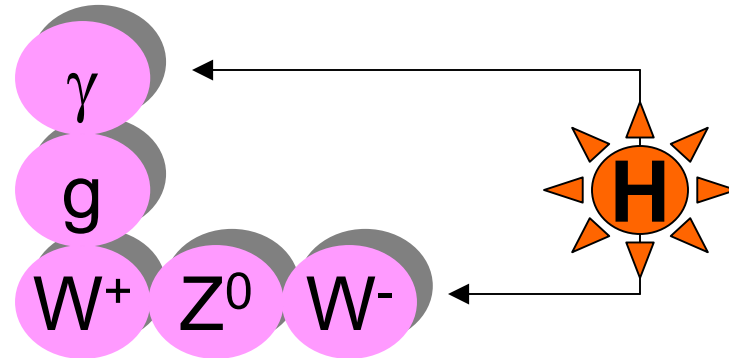
H Higgs

We'll come back to this guy later

Relative strengths

Particle Accelerators

- **Accelerators allow us to explore the interactions of particles at high energies**
  - **See the underlying physics not the dressing**
- **We can collide beams of either electrons or protons**
  - **Because electron beams radiate when accelerated, proton accelerators are the best way to reach very high energies (electron accelerators play an important complementary role)**
- **Proton-antiproton collision:**

Underlying Event

Hard Scatter
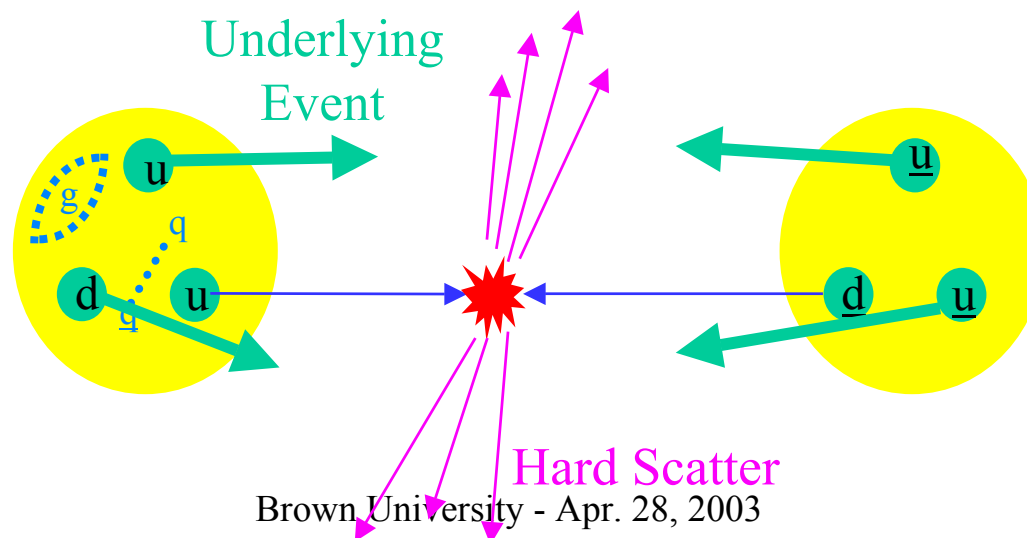
Colliders

Hadron-Hadron

- **Past**
  - **ISR at CERN**
  - **SPS at CERN**

- **Present**
  - **Tevatron at Fermilab**

- **Future**
  - **LHC at CERN**

- **Emphasis on maximum energy = maximum physics reach for new discoveries**

Electron-Positron

- **Past**
  - **SPEAR at SLAC**
  - **PETRA at DESY**
  - **. . .**

- **"Present" (recently ended)**
  - **LEP at CERN**

- **Future**
  - **Linear Collider**

- **Emphasis on precision measurements**

Both approaches are complementary

Fermilab

Batavia, Illinois

Chicago

CDF

DØ

Booster

Tevatron

p

p̄

p̄ source

Main Injector & Recycler
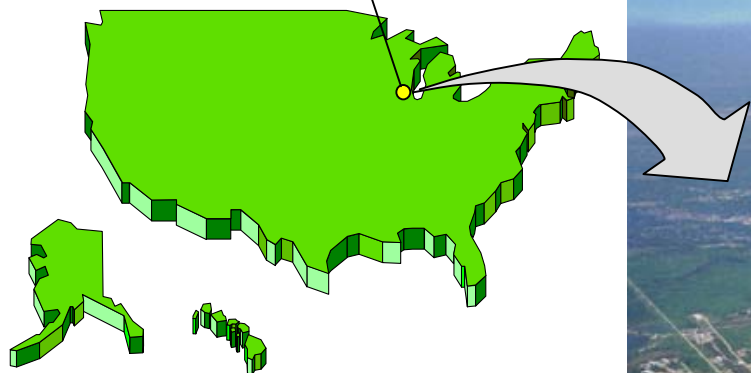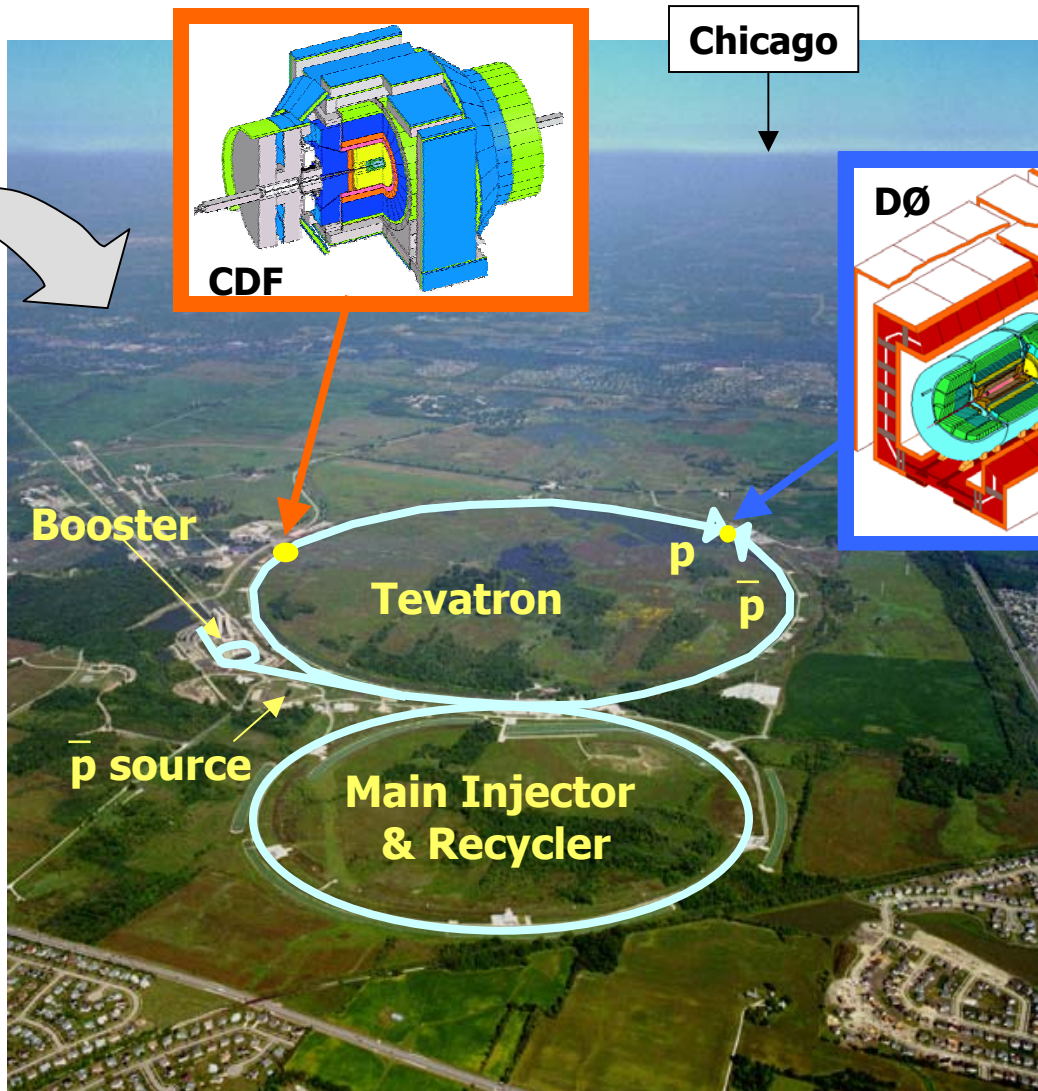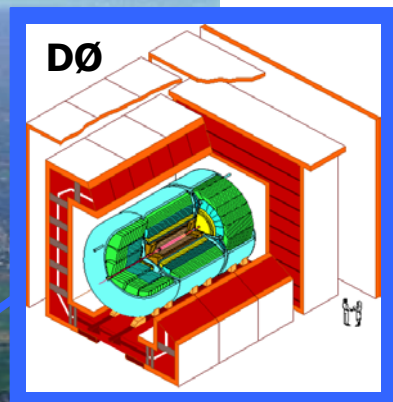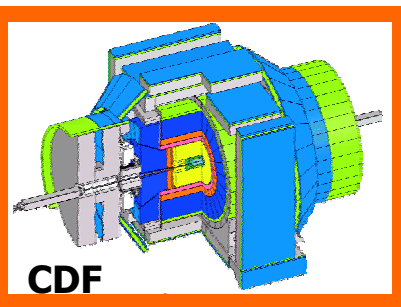
p → 💥 ← p̄

$\sqrt{s} = 1.96$ TeV
$\Delta t = 396$ ns

Run I 1992-96
Run II 2001-10
100 × larger dataset
increased energy
better detectors

What is DØ ?

Collider Detector at DZero interaction region

- **Truly International collaboration**
  - **18 countries**
  - **35 US, 41 non-US institutions**
  - **646 physicists – 334/312 US/non-US**

The DØ Collaboration

- **Run II started on March '01**
- **Detector commissioning (almost) completed**
- **Rich physics program**
  QCD, WZ, B, Top, Higgs, and New Phenomena

DØ History

1985   1990   1995   2000

Peak Construction 1988-1991

Data Taking 1992-1996 (Run I)

Roll In January 2001 (Run II…)

Baseline Approval from DOE Nov. 1984

Roll In February 1992 Good Beam Sept. 1992

Upgrade Detector to Utilize Main Injector Upgrade 1996-2000

Design Collision Hall, Do Detector R&D (First Calorimeter Using Liquid Argon) 1985-1987

First Meeting Stony Brook July 1983

☆ - **Fall 1993, First DØ Paper**

★ - **March 1995, Discovery of Top**

★ - **Fall 2000, 100th DØ Paper (130th Ph.D.)**

★ - **July '02, First Run II Physics Results**

? - March 2005, Discovery of …

DØ Detector

Calorimeters

Tracker

Muon System

protons

antiprotons

Beamline Shielding

Electronics

20 m

DØ Detector Installation

DØ detector installed in the Collision Hall, January 2001

What do HEP physicists actually do?

- **Design and build hardware (Detectors & electronics)**
- **Write software**
- **Operate the detector**
- **Interpret data**
- **Present, refine, discuss our results among ourselves**
- **Present and discuss results at conferences**
- **Publish papers**
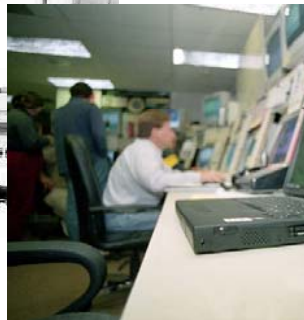
Theory - Experiment

- **You've got this great standard model and you know all about all of the particles and forces involved. So why do you need to do these experiments? Isn't it all done?**

- **Yes, we know a lot, but we know a lot less than we would like, and we know enough now to ask some deeper questions**
  - **the paradox of the "circumference of knowledge"**

  Not just "what happens?" type of questions — "why does it happen?"

For example

- **Why are some forces weak and others strong?**

- **What is the dark matter that seems to be responsible for cosmic structure?**

- **What is the structure of spacetime?**

Not purely particle physics questions any more
Particle physics is the DNA of the universe

Q:

- **Why are some forces weak and others strong?**
  - **Is the Universe filled with an energy field?**
  - **Is there a unification of forces at very high energies?** *(We'll come back to this later in the talk)*

Electroweak Symmetry Breaking

- **Photons and W/Z bosons couple to particles with the same strength**
  - **Electroweak unification**
- **Yet while the universe (and this room) is filled with photons, W's and Z's mediate a weak force that occurs inside nuclei in radioactive beta decay**
  - **This is because the W and Z are massive particles**
  - **The unification is "broken"**
- **Where does this mass (the symmetry breaking) come from?**
  - **Not like the mass of the proton, which is the binding energy of its constituents**
- **In the Standard Model, the W and Z get their mass because the universe is filled with an energy field, called the Higgs field, with which they interact (and in fact mix)**
  - **The universe is a refractive medium for W's and Z's**

What does mass mean?

- **For an elementary pointlike particle**
    - propagates through the vacuum at v < c
    - Lorentz transform mixes LH and RH helicity states: symmetry is broken
        - mass is equivalent to an interaction with the (Quantum Mechanical) vacuum (a "refractive index")
        - coupling strength = mass

- **For a spin-1 state like a photon, there is an extra effect**
    - massless → two polarization states
    - massive → three polarization states
        - where does this additional degree of freedom come from?

Massless field
Something else
mix →
Massive field
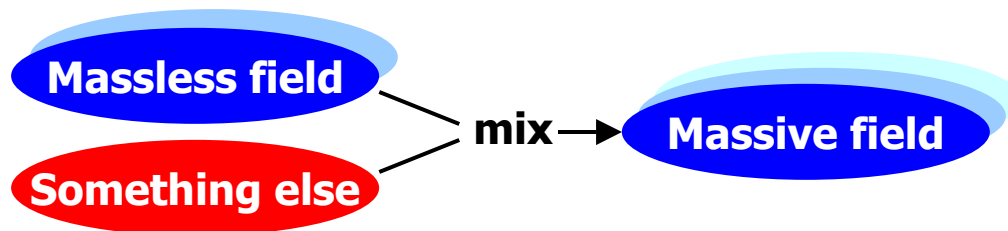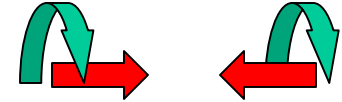
The "Higgs Mechanism"
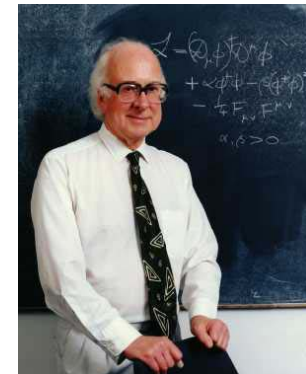
The Higgs Mechanism

- **Hence, in the Standard Model**
  (Glashow, Weinberg, Salam, 't Hooft, Veltmann)
  - "electroweak symmetry breaking" through introduction of a scalar field which permeates all of space with a finite vacuum expectation value
    - Cosmological implications!
    - How can we relate this with "Dark Energy?"
  - If the same field couples to fermions → generates fermion masses

- **An appealing picture: is it correct?**
  - One clear and testable prediction: there exists a **neutral scalar particle** which is an excitation of the Higgs field

    We want to excite this field in the lab and study its quanta!
    "Pluck the violin-string of the universe"

  - All its properties (production and decay rates, couplings) are fixed within the SM, except for its own mass

Searching for the Higgs

- **In the last decade, the focus was on experiments at the LEP e⁺e⁻ collider at CERN (European Laboratory for Particle Physics)**
  - precision measurements of parameters of the W and Z bosons, combined with Fermilab's top quark mass measurements, set an upper limit of $m_H \sim 200$ GeV
  - direct searches for Higgs production exclude $m_H < 114$ GeV

- **Summer 2000: Hints of a Higgs (?)**
  - the LEP data may be giving some indication of a Higgs with mass 115 GeV (right at the limit of sensitivity)
  - despite these hints, CERN management decided to shut off LEP operations in order to start construction on the Large Hadron Collider (a new accelerator with seven times the energy of the Tevatron)

- **Until the end of the decade, Fermilab has a unique opportunity to discover or exclude this object**

114 GeV   200 GeV

theory uncertainty

$\Delta\alpha_{had}^{(5)} =$
— 0.02804±0.00065
---- 0.02755±0.00046

$\Delta\chi^2$

Excluded   Preliminary

m_H [GeV]
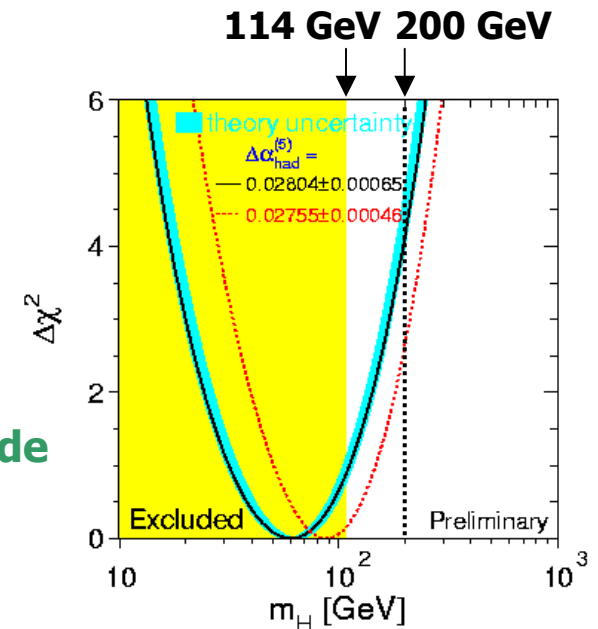
Look who is interested…
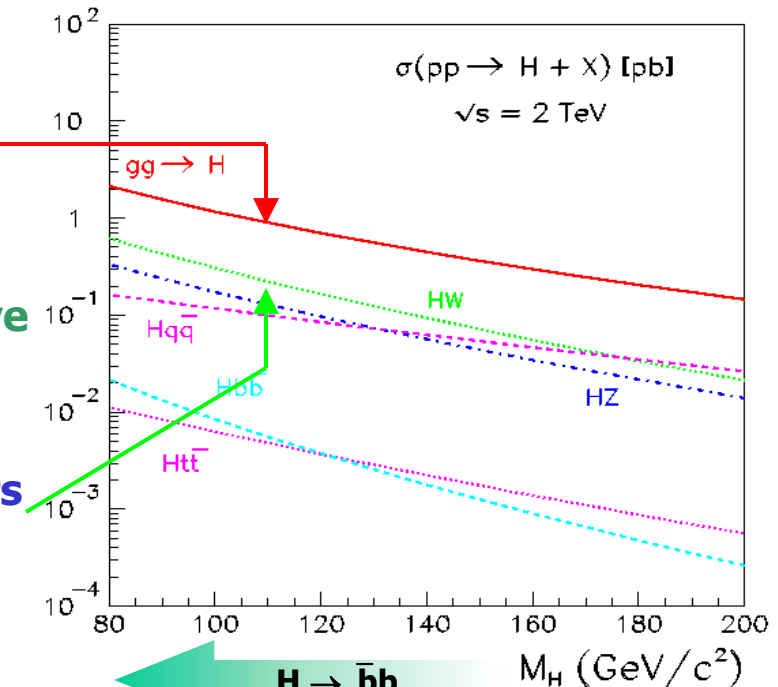
What's on the web?

www.higgsboson.com

- **Higgs Boson is the name of a British musician**

Higgs Hunting at the Tevatron

- **For any given Higgs mass, the production cross section and decays are all calculable within the Standard Model**

- **Inclusive Higgs cross section is quite high: ~ 1pb**
    - **for masses below ~ 140 GeV, the dominant decay is H → bb which is swamped by background**
    - **at higher masses, can use inclusive production plus WW decays**

- **The best bet below ~ 140 GeV appears to be associated production of H plus a W or Z**
    - **leptonic decays of W/Z help give the needed background rejection**
    - **cross section ~ 0.2 pb**

$\sigma(pp \to H + X)$ [pb]

$\sqrt{s} = 2$ TeV

$gg \to H$

HW

Hqq̄

Hbb

HZ

Htt̄

M_H (GeV/c²)

$H \to \bar{b}b$

$H \to WW$

Dominant decay mode

Boaz Klima (FNAL)

Example: m_H = 115 GeV

- ~ 2 fb^{-1}/expt (2005): exclude at 95% CL
- ~ 5 fb^{-1}/expt (2008): evidence at 3σ level
- ~ 10 fb^{-1}/expt (2010): expect a 5σ signal

Every factor of two in luminosity yields a lot more physics

- Events in one experiment with 15 fb^{-1}:

Mode	Signal	Background	S/√B
lνbb	92	450	4.3
$\nu\nu$bb	90	880	3.0
llbb	10	44	1.5

- If we do see something, we will want to test whether it is really a Higgs by measuring:
  - mass
  - production cross section
  - Can we see H $\rightarrow$ WW? (Branching Ratio ~ 9%)
  - Can we see H $\rightarrow$ $\tau\tau$? (Branching Ratio ~ 8%)

What if we see nothing?

As long as we have adequate sensitivity, exclusion of a Higgs would itself be a very important discovery for the Tevatron
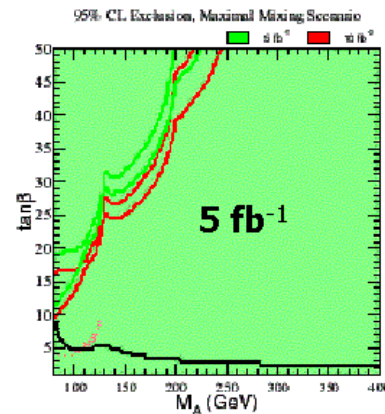
- **In the SM, can exclude most of the allowed mass range**
- **If supersymmetry (SUSY) is correct, we can potentially exclude <u>all</u> the remaining parameter space**
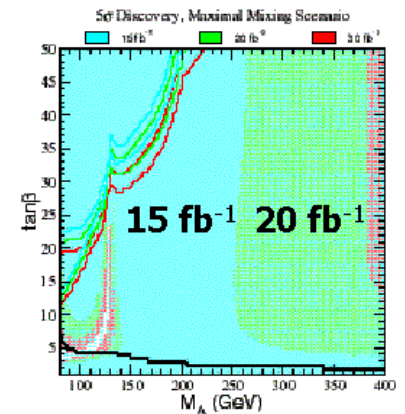- **Would certainly make life "interesting" for the theorists**

THE BEST OF MARTHA STEWART LIVING
good things
a collection of inspired household ideas and projects

It's a good thing

m_H probability density, J. Erler (hep-ph/0010153)

Exclude H_{SM} with:

| 5 | 10 | 5 | fb^{-1} |

95% exclusion

95% CL Exclusion, Maximal Mixing Scenario

5 fb^{-1}

5σ discovery

5σ Discovery, Maximal Mixing Scenario

15 fb^{-1} 20 fb^{-1}
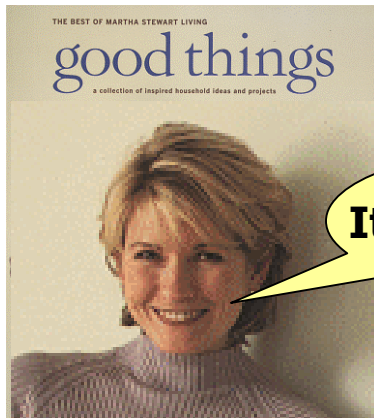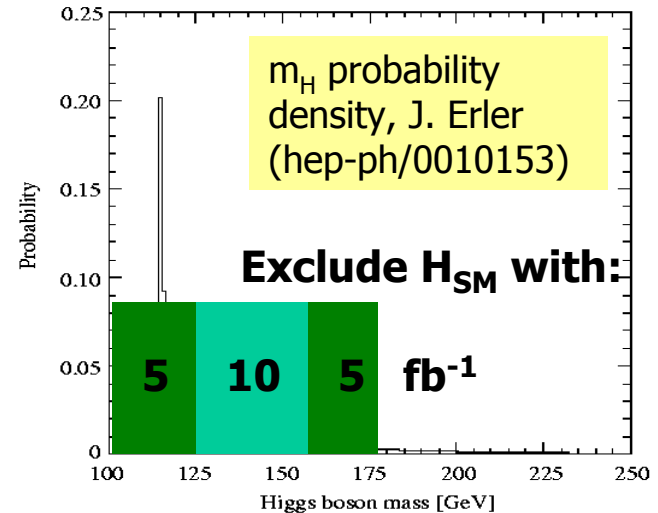
Exclusion and discovery for SUSY Higgs sector, maximal stop mixing, sparticle masses = 1 TeV

Q:

- **What is the dark matter that seems to be responsible for structure in the universe?**

    - **Is it a new kind of particle?**

    - **Does this point to a previously undiscovered symmetry of the universe?**

Mass shapes the Universe

...through gravitation, the only force that is important over astronomical distances

- **Masses of Atoms**
  - **binding energies from the strong force (QCD)**
- **Dark Matter (DM)**
  - **Long known that dynamical mass much greater than visible luminous material**
  - **Primordial nucleosynthesis, D/He abundance measures baryon density**

Cosmic Microwave Background

- **Recent measurements of "acoustic peaks" vs. multipole number**

WMAP 2003

TT Cross Power
Spectrum

Λ - CDM All Data
WMAP
CBI
ACBAR
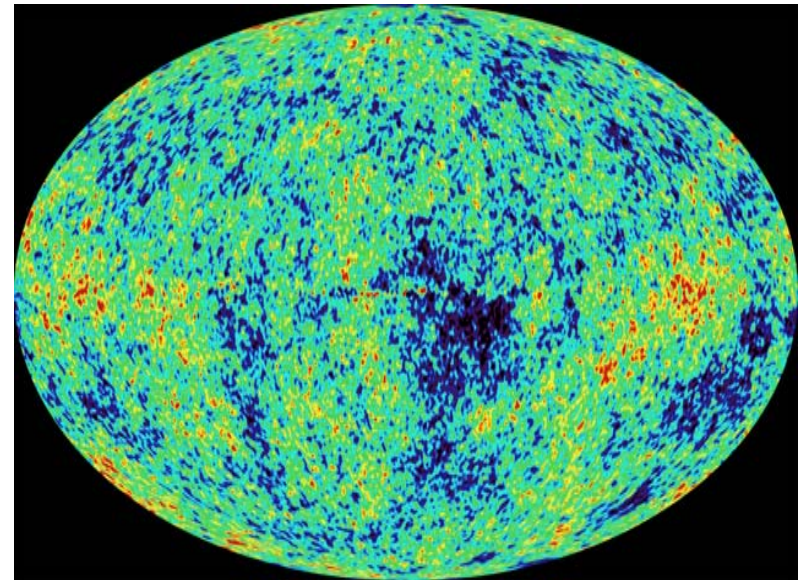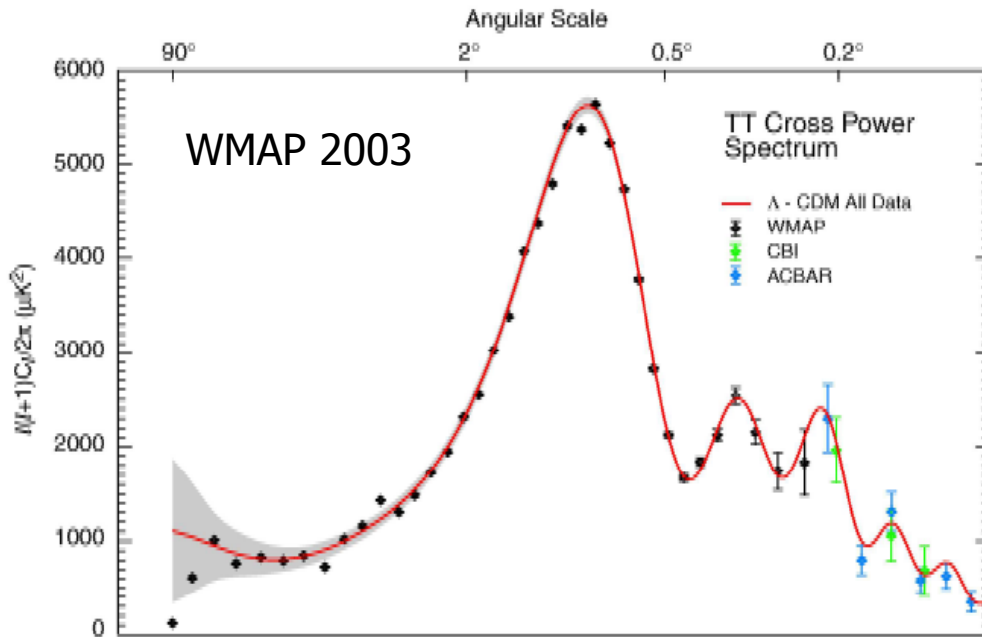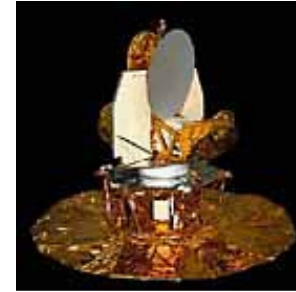
What is Dark Matter?

Compare with cosmological models

- **Size of DM "potential wells" into which matter fell**
- **Allows matter and DM densities to be extracted**

→ **About six to seven times more mass (27±4%) than there is baryonic matter (4.4±0.4%)**

- **new particles?**
  - **Weakly interacting, massive relics from the very early universe**

- **Two experimental approaches:**
  - **Search for dark matter particles impinging on earth**
  - **Try to create such particles in our labs/accelerators**

Supersymmetry

Particles

Supersymmetric "shadow" particles

- **Postulate a symmetry between bosons and fermions:**
  - all the presently observed particles have new, more massive superpartners (SUSY is a broken symmetry)
- **Theoretically nice:**
  - additional particles cancel divergences in the Higgs mass
    - **solves a deficiency of the SM**
  - closely approximates the standard model at low energies
  - allows unification of forces at much higher energies
  - provides a path to the incorporation of gravity and string theory: Local Supersymmetry = Supergravity
- **Predicts multiple Higgs bosons, strongly interacting squarks and gluinos, and electroweakly interacting sleptons, charginos and neutralinos**
  - masses depend on unknown parameters, but expected to be 100 GeV - 1 TeV
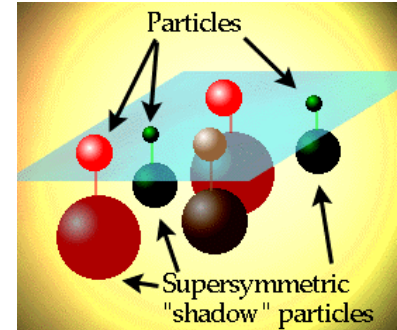
**Lightest neutralino is a good explanation for cosmic dark matter
Potentially discoverable at the Tevatron**

Supersymmetry signatures

- **Squarks and gluinos are the most copiously produced SUSY particles**
- **As long as R-parity is conserved, cannot decay to normal particles**
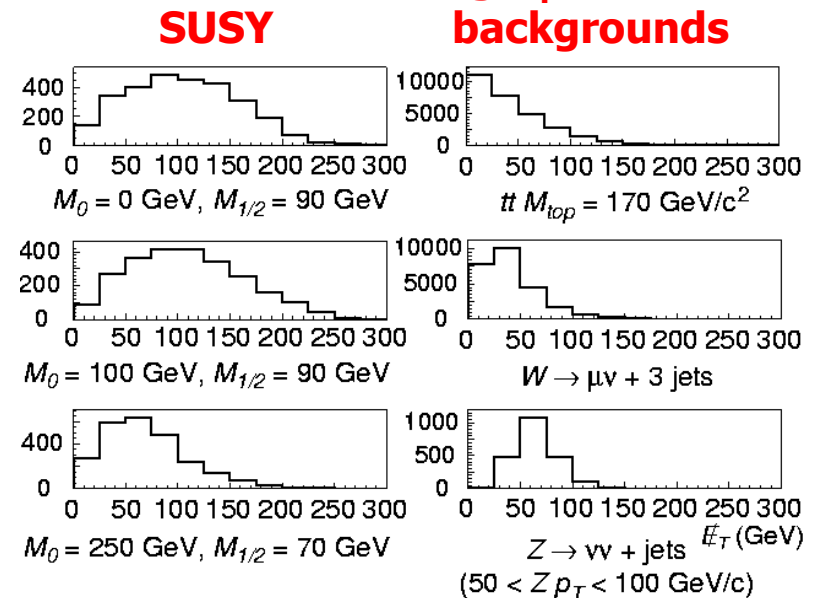 - **missing transverse energy from escaping neutralinos (lightest supersymmetric particle or LSP)**

Make dark matter at the Tevatron! ⟶ **Detect its escape from the detector**
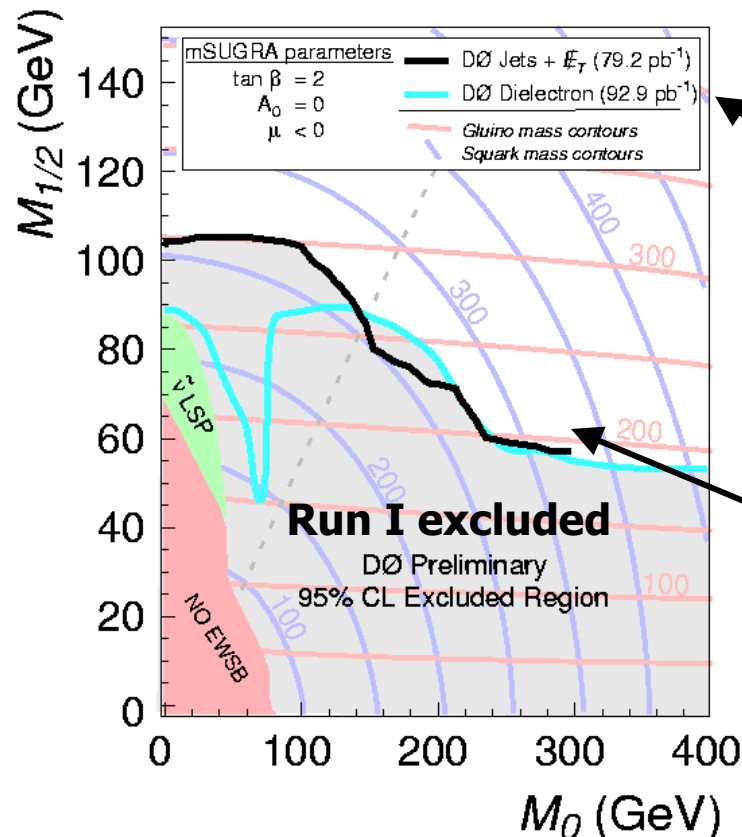
Possible decay chains always end in the LSP

Missing E_T

SUSY   **backgrounds**

$M_0 = 0$ GeV, $M_{1/2} = 90$ GeV

tt $M_{top} = 170$ GeV/c^2

$M_0 = 100$ GeV, $M_{1/2} = 90$ GeV

$W \rightarrow \mu\nu$ + 3 jets

$M_0 = 250$ GeV, $M_{1/2} = 70$ GeV

$Z \rightarrow \nu\nu$ + jets
$(50 < Z\, p_T < 100$ GeV/c)

$\not{E}_T$ (GeV)
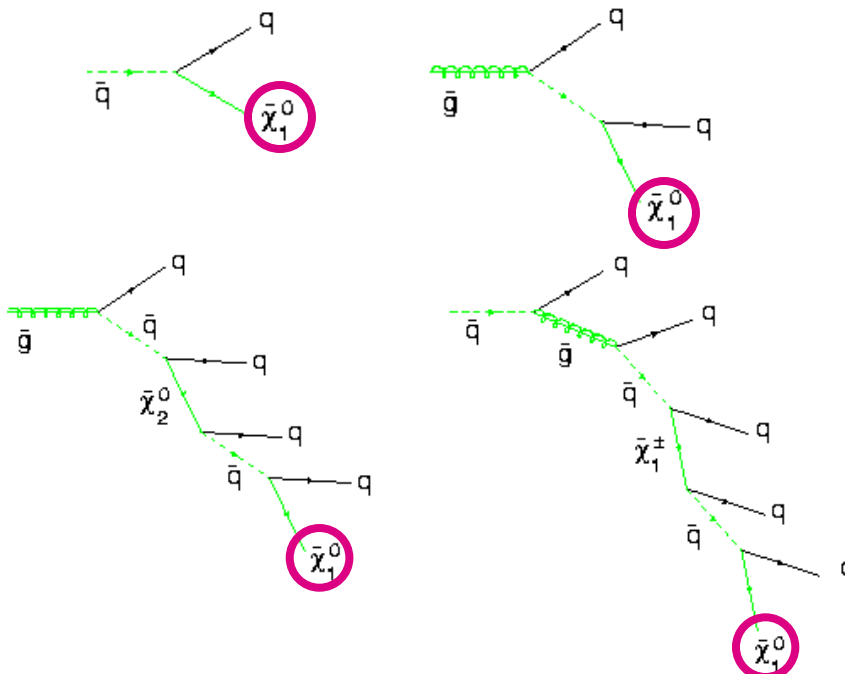
Search region typically > 75 GeV

Search for squarks and gluinos

- **Two complementary searches**
  - **jets plus missing E_T and no electrons/muons**
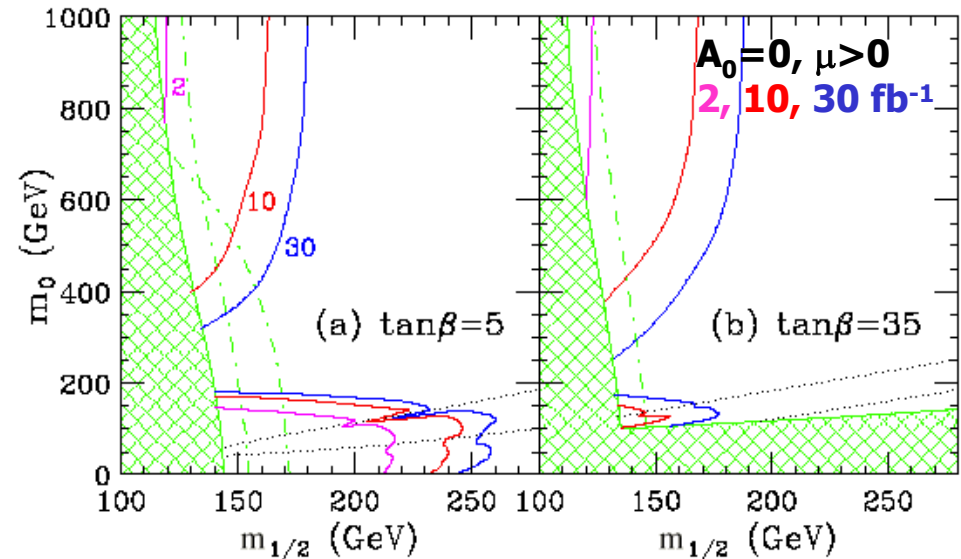 - **2 electrons, 2 jets + Missing E_T**

Reach with 2 fb^{-1}: gluino mass ~ 400 GeV

Run I (1992-95) gluino ~ 200 GeV squark ~ 250 GeV

Missing Transverse Energy

Chargino/neutralino production

- **"Golden" signature**
  - **Three leptons**
    - **very low standard model backgrounds**

- **This channel becomes increasingly important as squark/gluino production reaches its kinematic limits (masses ~ 400-500 GeV)**

- **Reach on $\chi^{\pm}$ mass**   **~ 180 GeV (tan β = 2, μ< 0)**
  ~ 150 GeV (large tan β)

A_0=0, μ>0
2, 10, 30 fb^{-1}

(a) tanβ=5

(b) tanβ=35

m_0 (GeV)

$m_{1/2}$ (GeV)
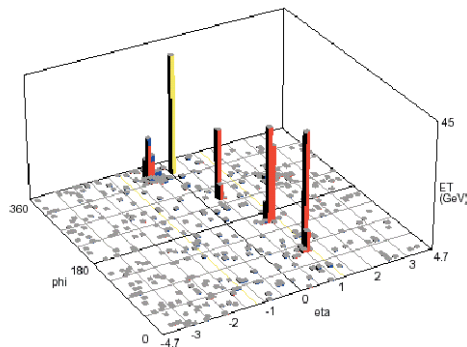
Searches have begun!
So far number of events is consistent with expectations — we need a lot more data, but the tools are in place

Q:

- **What is the structure of spacetime?**
  - **How many dimensions are there?**
  - **Is geometry the way to connect gravity to the other forces?**

Connections with Gravity

- **While supersymmetry is required for supergravity, it was usually assumed that any unification of forces would occur at the Planck scale ~ 10^{19} GeV**
  - very large hierarchy between the electroweak scale and gravitational scales

- **Powerful new idea:**
  Gravity may propagate in extra dimensions, while the gauge particles and fermions (i.e. us) remain trapped in 3+1 dimensional spacetime
  - extra dimensions not necessarily small in size (millimeters!)
  - true Planck scale may be as low as the electroweak scale
  - Gravity could start to play a role in experiments at ~ TeV

- **Many different theoretical ideas, with different topologies possible**
  - large extra dimensions (ADD)
  - TeV scale extra dimensions
  - warped extra dimension (RS)

It's already out there…

A Far-Out Theory Describing What's Out There

Physicists have long sought a unified theory to explain all the forces and matter in the universe. Superstring theory is an attempt at such a unification, and now "brane" theory expands on it, proposing that our universe is one of many membranes that "float" in a multidimensional megaverse.

SUPERSTRING THEORY
At its most basic level, the universe consists of tiny loops of string that vibrate at different frequencies.

Since matter can be described in terms of energy, each frequency (energy) corresponds to a type of particle (matter) just as different frequencies coming from a violin's strings produce different notes.

STRING SIZE
The strings are to an atom…

…as an atom is to the solar system.
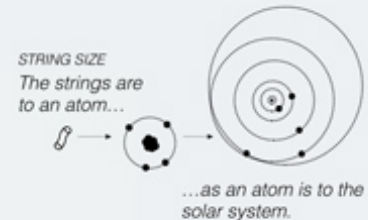
Brane Theory
It expands superstring theory to include vibrating membranes, or branes, which may have many dimensions.

❶ Our universe can be thought of as a three-dimensional brane floating inside a four-dimensional megaverse.

❷ Most strings that compose our universe are attached to the brane's surface, and so most particles that exist on our brane are confined to its three-dimensional space.

❸ However, the particles that convey gravity, gravitons, are not tightly confined to any particular brane, and some of them roam across to other branes in the megaverse.

Sources: "Q is for Quantum," by John Gribbin; "The Ideas of Particle Physics," by J.E. Dodd

THE MEGAVERSE

ANOTHER BRANE

GRAVITONS

SPACE-TIME CURVATURE

GRAVITONS

OUR UNIVERSE (BRANE)

DARK MATTER
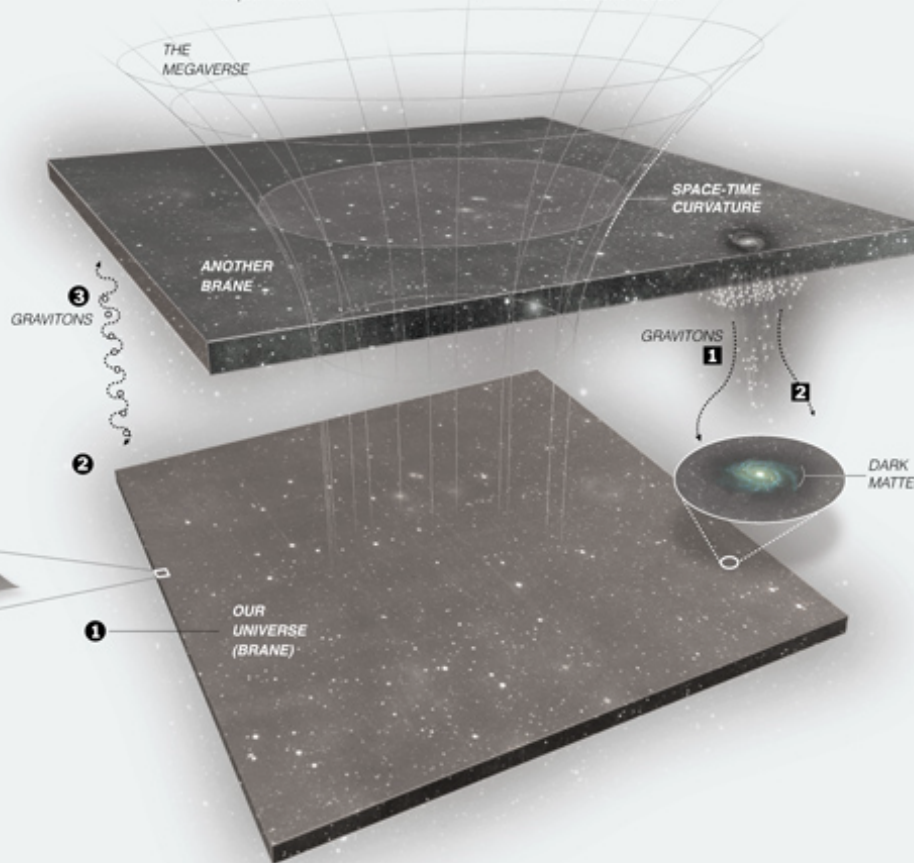
BRANE THEORY AND GRAVITY
Gravity is described by relativity theory as curved space-time, and it is the weakest of the forces in our universe. Brane theory contains a possible explanation.

❶ Gravitons, conveyors of gravity, may be concentrated on a different brane where the space-time of the megaverse is severely curved. Only a small number of gravitons make their way here, so gravity is felt as a weak force.

DARK MATTER
Cosmologists suggest that it makes up 90 percent of our universe. It neither emits or absorbs light, but it exerts gravity. According to brane theory, it may just be ordinary matter concentrated on other branes, and its light cannot shine through to this universe.

❷ The light from dark matter, conveyed by particles called photons, would cling to the surface of the foreign brane, but gravitons might seep across the divide. Pulled by our galaxies' local gravitational force, the gravitons would cluster into halos around the galaxies.
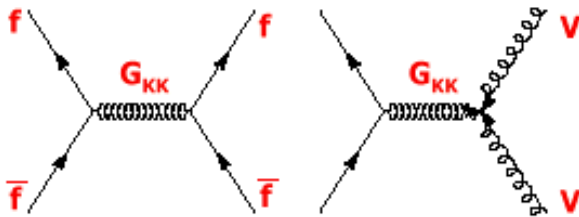
Steve Duenes/The New York Times

TeV-scale gravity

- **Observable effects can be direct and spectacular . . .**
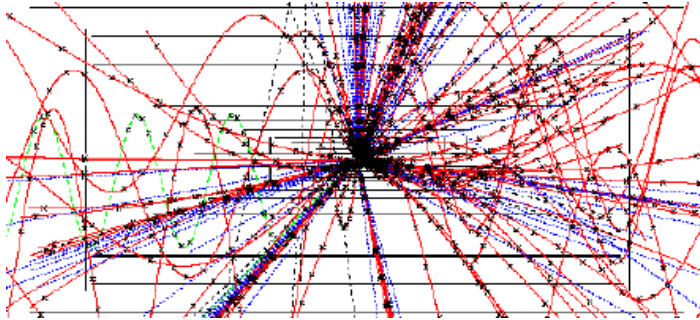
Production of Black Holes may even occur

Decay extremely rapidly (Hawking radiation) with spectacular signatures
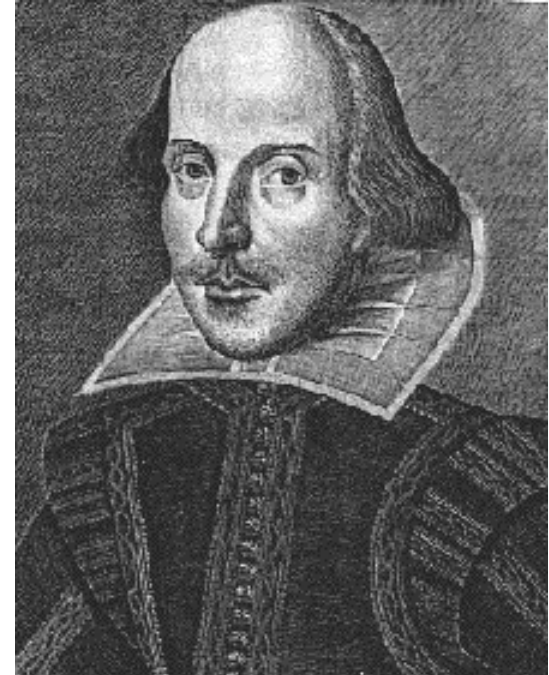
- **Or indirect . . .**
  - **Virtual graviton exchange can enhance the production rate for e^+e^- and $\gamma\gamma$ pairs with large masses and angle relative to the beamline**
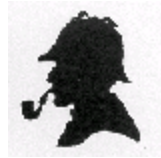

- **We have started this analysis with Run II data**

Are we asking the right questions?

There are more things in heaven and earth, Horatio,
Than are dreamt of in your philosophy. — *W.S.*

- **We need a way to search for new phenomena that is not constrained by our preconceptions of what might be "out there."**

Sleuth

- **A new approach from DØ: attempt at a model-independent analysis framework to search for new physics**
  - will never be as sensitive to a particular model as a targeted search, but open to anything
  - searches for deviations from standard model predictions
- **Systematic study of 32 final states involving electrons, muons, photons, W's, Z's, jets and missing E_T in the DØ 1992-95 data**
- **Only two channels with some hint of disagreement**
  - **2 electrons + 4 jets**
    - **observe 3, expect 0.6± 0.2, CL = 0.04**
  - **2 electrons + 4 jets + Missing E_T**
    - **observe 1, expect 0.06±0.03, CL = 0.06**
- **While interesting, these events are not an indication of new physics, given the large number of channels searched**
  - 89% probability of agreement with the Standard Model (alas!)

This approach will be extremely powerful in future!

DØ - where are we now?

- **The experiment is up and running efficiently**
- **We are collecting high-quality data at reasonable rates**
- **All data is being processed by the reconstruction program "online"**
- **Physics analyses are being performed in many areas**
  - **Re-establishing "old" measurements and limits**
  - **Testing the SM at a new/higher E_{CM}**
  - **New angles, new ideas,…**
  - **Looking for surprises – hints for physics beyond the SM**
- **It's very exciting**
- **It's going to get even more exciting!!**

DØ Integrated Luminosity

D0 Run IIa Integrated Luminosity

19 April 2002 - 19 April 2003

Luminosity (pb⁻¹) — $\text{Luminosity (pb}^{-1})$

Delivered values: 4.4, 14.8, 16.2, 25.4, 36.5, 52.9, 74.6, 95.2, 117.9, 126.7, 134.6, 149.3, 164.7

Physics values: 1.4, 4.0, 4.2, 9.6, 15.5, 25.2, 38.9, 53.8, 70.0, 77.0, 83.4, 95.3, 108.3

36 pb⁻¹ of Delivered Lumi from 7 June 2001 to 18 April 2002

Fully Inst. Tracker 19 Apr 2002

65.7% Average Efficiency

Current Efficiency ~85%

Tevatron Shutdown 13 Jan - 9 Feb & 2-10 March

2003 Winter Conference Data

~ 50 pb⁻¹

Boaz Klima (FNAL)

DØ Detector Performance

D0 Monthly Data Taking Efficiency — 19 April 2002 - 19 April 2003

Efficiency = (Recorded/Delivered) Luminosity

Month	Efficiency
Apr-02	0.410
May-02	0.293
Jun-02	0.391
Jul-02	0.587
Aug-02	0.572
Sep-02	0.620
Oct-02	0.643
Nov-02	0.749
Dec-02	0.773
Jan-03	0.791
Feb-03	0.821
Mar-03	0.821
Apr-03	0.845

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Brown University - Apr. 28, 2003

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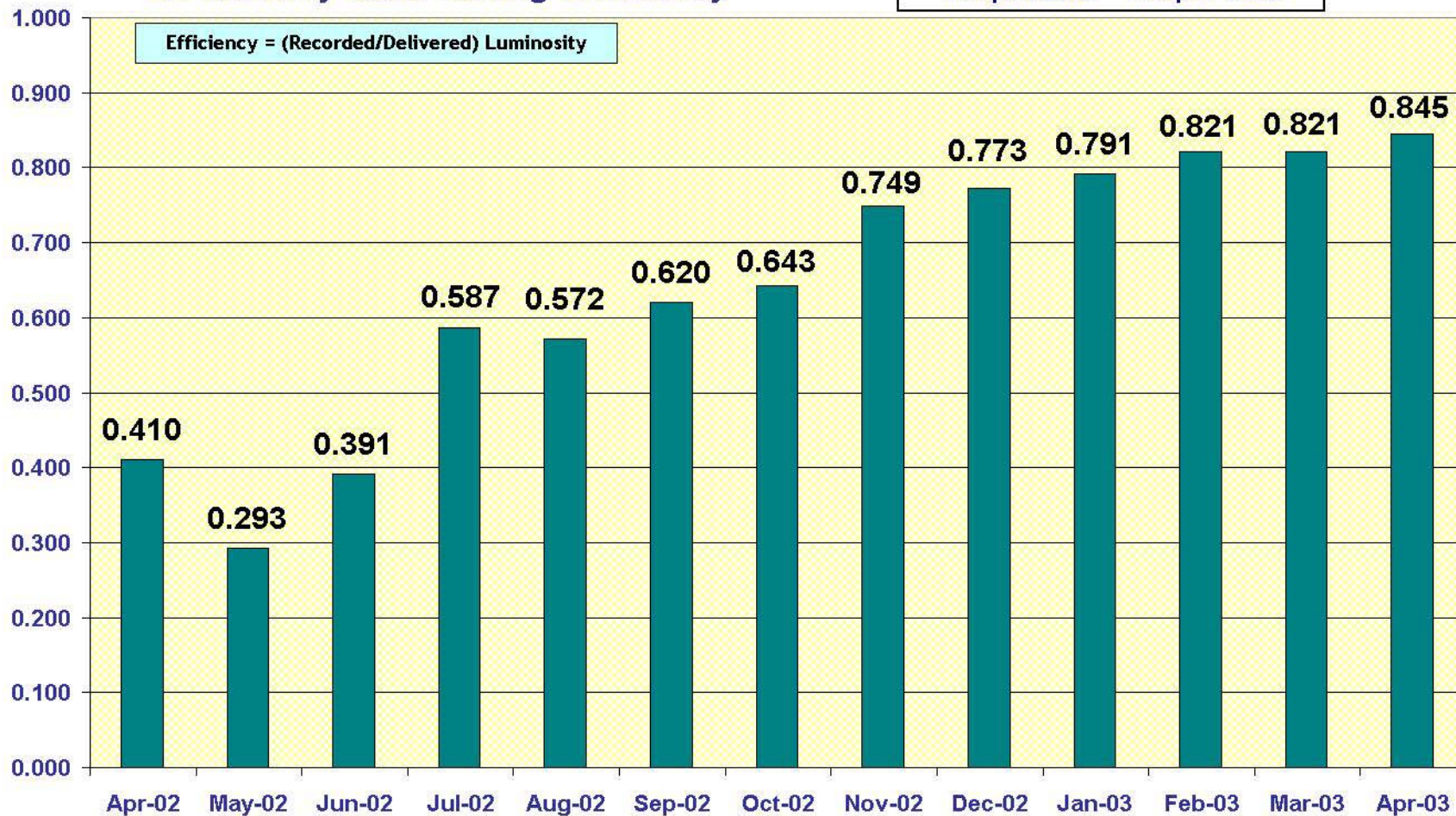
Most Recent Physics Results

• Many new results were presented at this year's major HEP conferences, e.g. Moriond & DPF in Mar.-Apr. '03

• A few results to be briefly summarized/mentioned here:

- Jets: inclusive jet cross-section

- B Physics: Strange and Beauty Particles, B lifetime, B_s and Λ_b

- W/Z Physics: cross section measurements

- Top Physics: cross section & mass measurements

- Higgs Searches: W/Z+H, H $\rightarrow$ WW*, H $\rightarrow \gamma\gamma$

- New Phenomena searches: SUSY, LQ, ED,…

• A lot more to come this summer…

• Even more in the next several years

Jets

- Inclusive jet cross section:
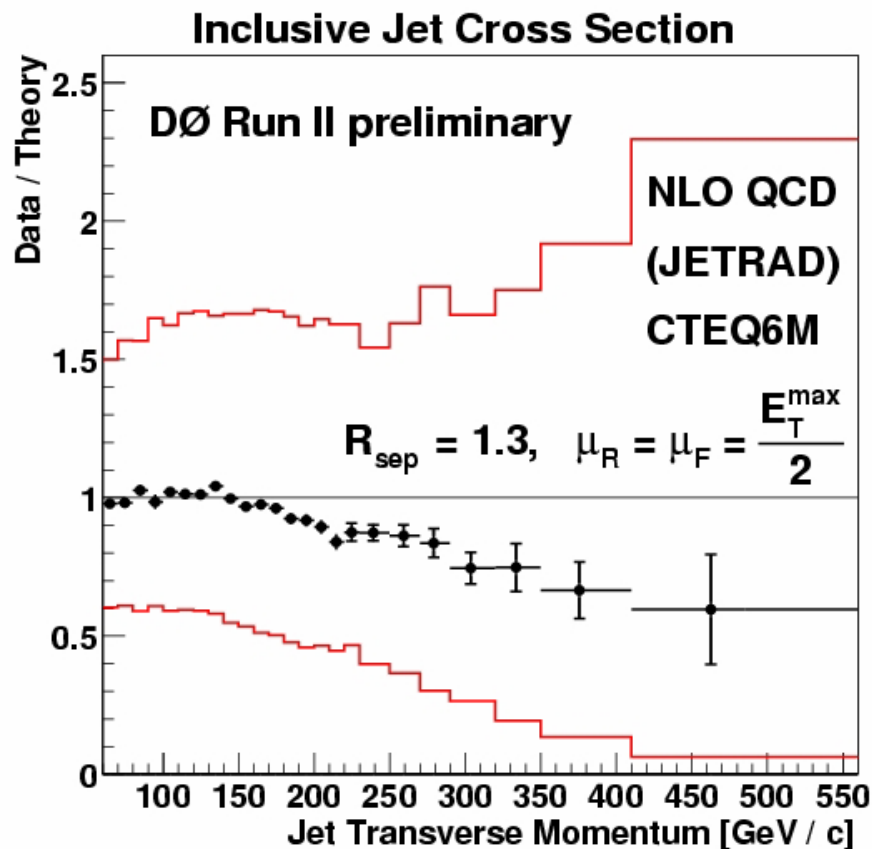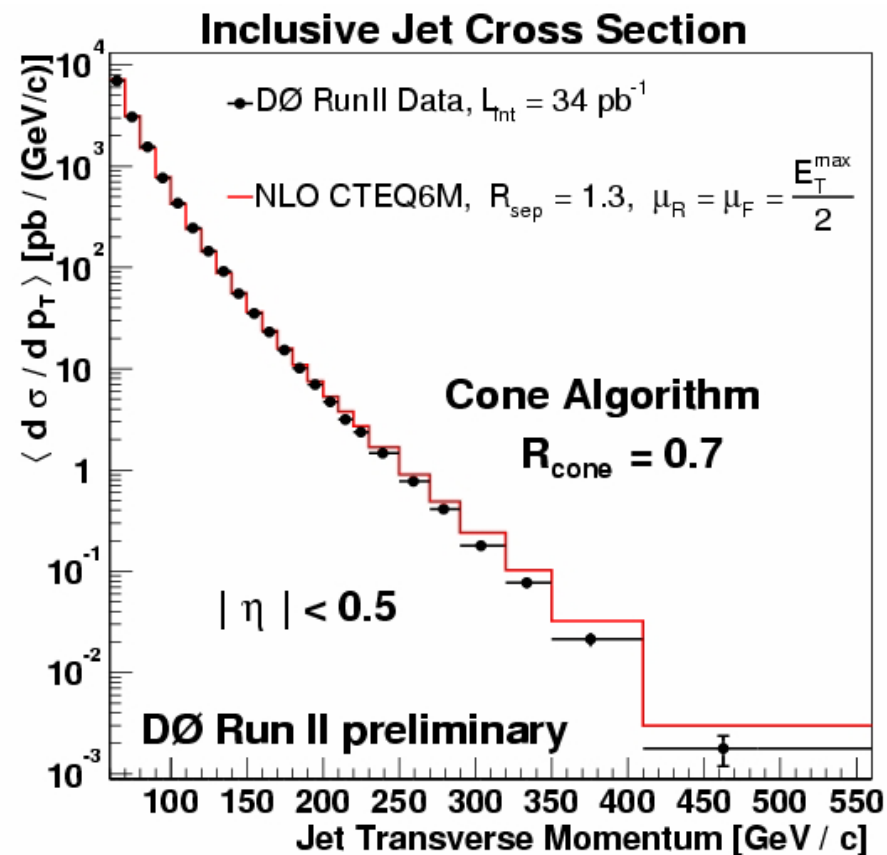
B Quark Physics
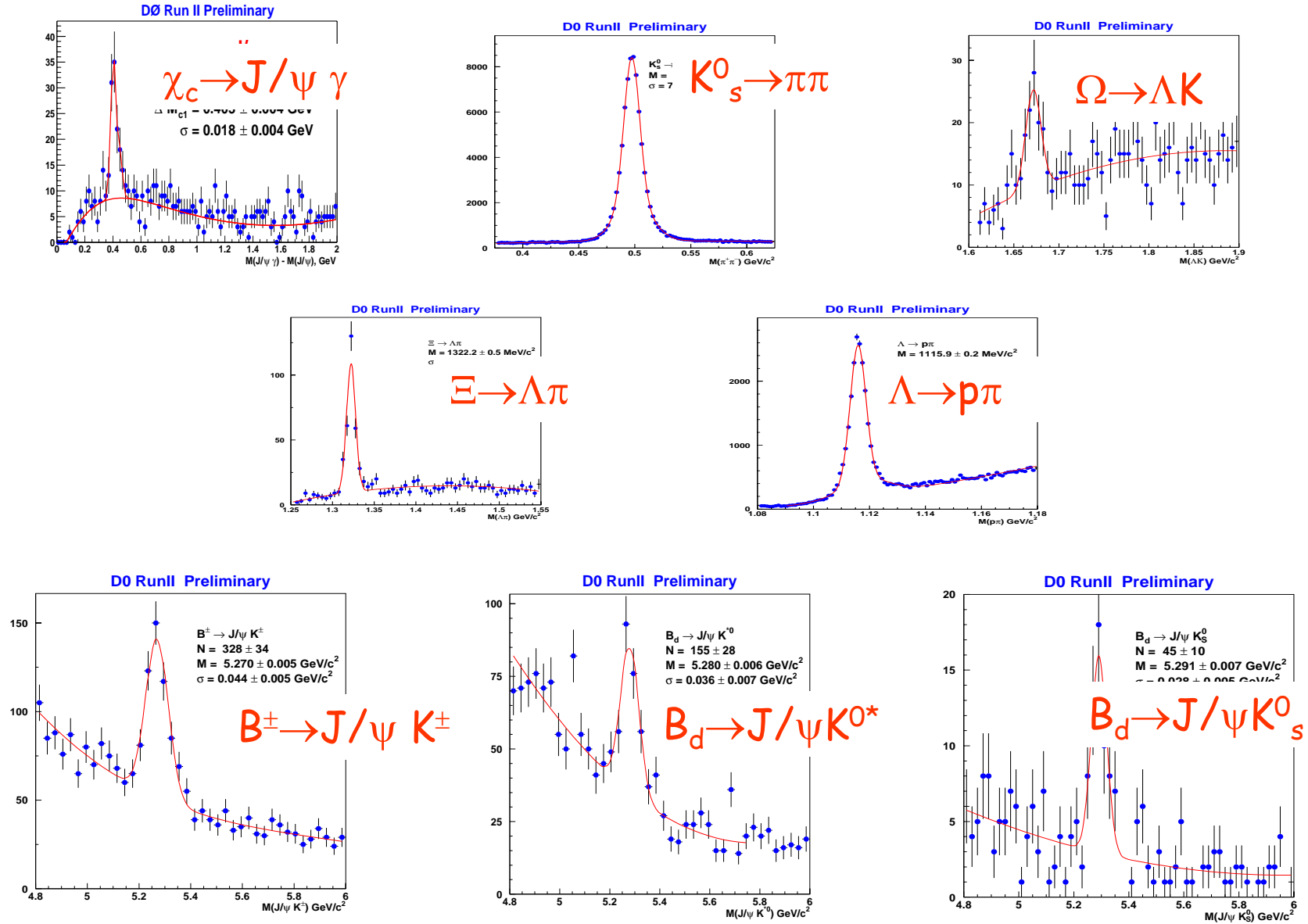
B Quark Physics

- B lifetimes:
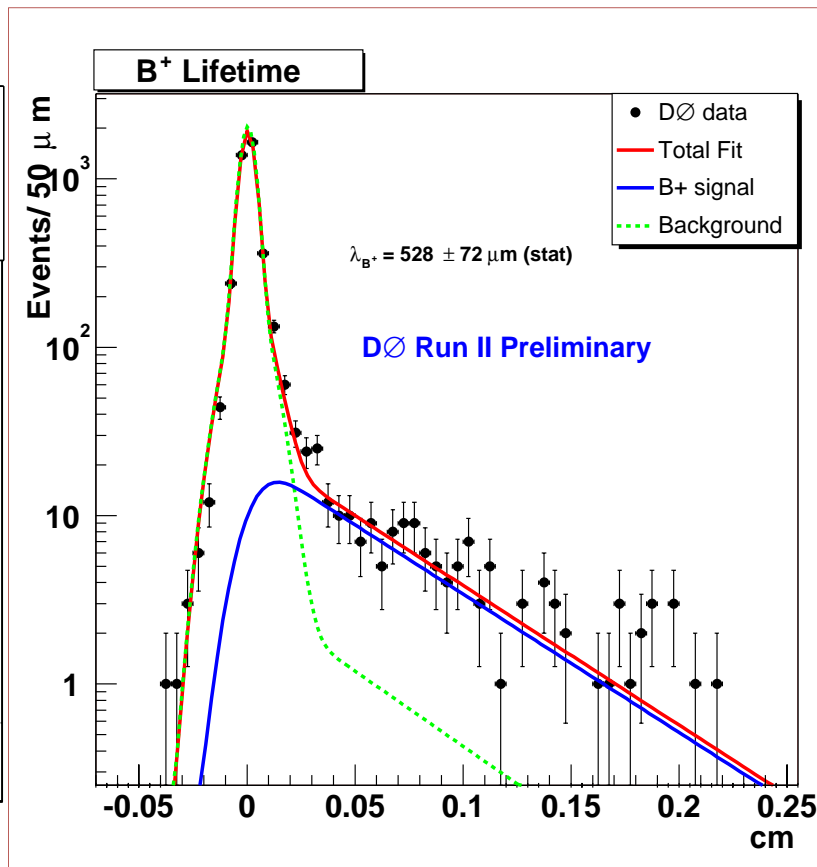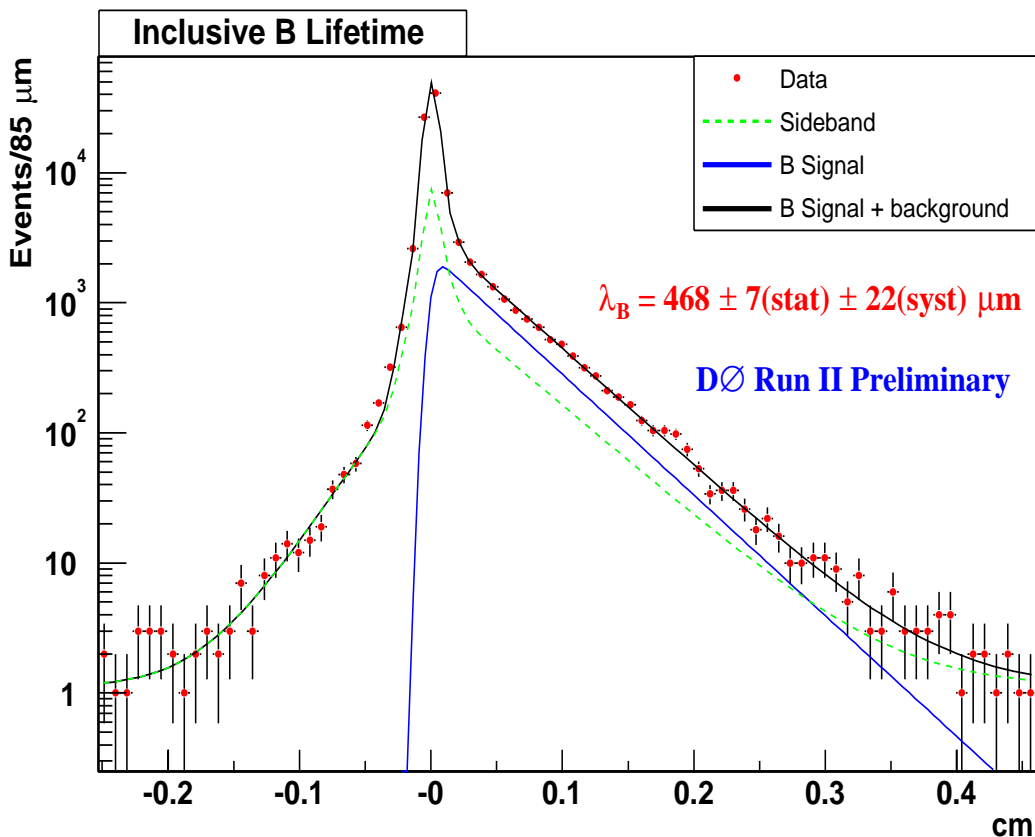
inclusive: $\langle\tau\rangle = 1.561 \pm 0.024$ (stat) ± 0.074 (sys) ps

charged B: $\langle\tau\rangle = 1.76 \pm 0.24$ (stat) ps

B Quark Physics

$\Lambda_b \rightarrow J/\psi \; \Lambda$

not accessible at B factories

lifetime: discrepancy with theory

$$\text{for} \quad \frac{\tau(\Lambda_b)}{\tau(B^0)}$$
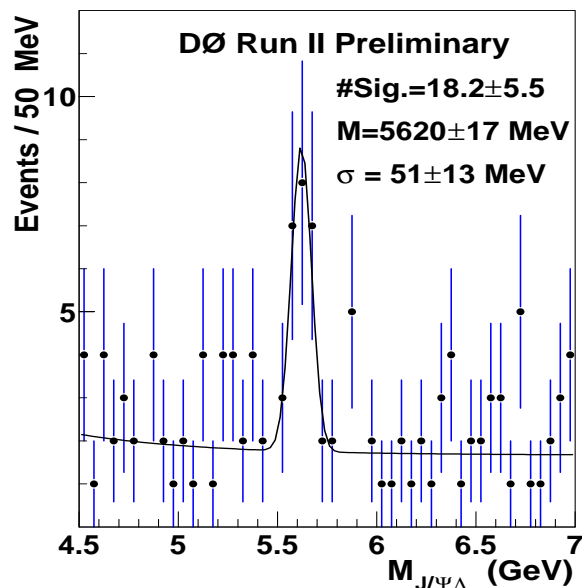
$B_s \rightarrow J/\psi + \phi$

not accessible at B factories

golden channel for CP violation in B_s system (very small in the SM)

DØ Run II Preliminary

#Sig.=18.2±5.5
M=5620±17 MeV
σ = 51±13 MeV

D0 RunII Preliminary

$B_s \rightarrow J/\psi \; \phi$
N = 62 ± 12
M = 5.360 ± 0.005 GeV/c^2
σ = 0.028 ± 0.005 GeV/c^2

5.31 < M(B$_s$) < 5.41 GeV/c^2
N = 50 ± 11
M = 1.0205 ± 0.0008 GeV/c^2
σ = 0.0041 ± 0.0010 GeV/c^2
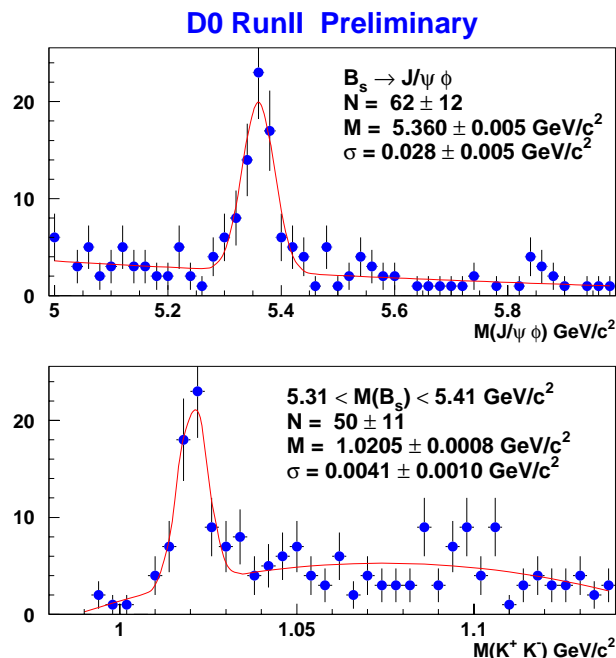
ElectroWeak Physics

- ## W/Z production

  $\rightarrow$ test of the SM, precision EW measurement

  $\rightarrow$ W + jets: background for Top and Higgs

  $\rightarrow$ Ws can be used to determine the luminosity

  $\rightarrow$ clean sample to tune algorithms and triggers

- ## Signal:

  $\rightarrow$ dominant production via $q\bar{q}$ annihilation

  $\rightarrow$ signature: high P_T e or μ + $\not{E}_T$ (W)

  high P_T di-lepton (Z)

  $\rightarrow$ background: QCD (fake leptons)
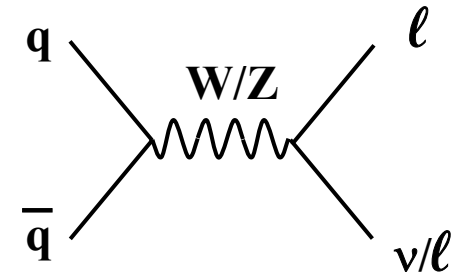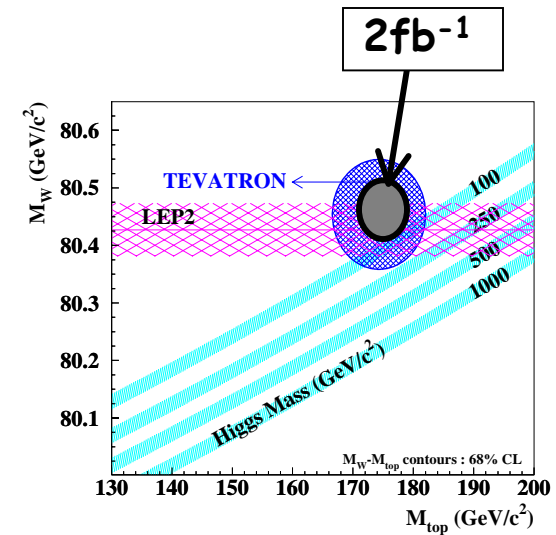
ElectroWeak Physics

$$\mathcal{L} \approx 42 \text{ pb}^{-1}$$

$$\mathcal{L} \approx 17 \text{ pb}^{-1}$$

$$\mathcal{L} \approx 32 \text{ pb}^{-1}$$

W→ eν
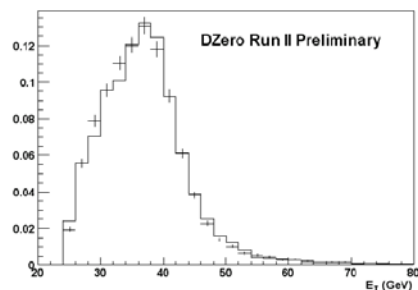
Z→ee
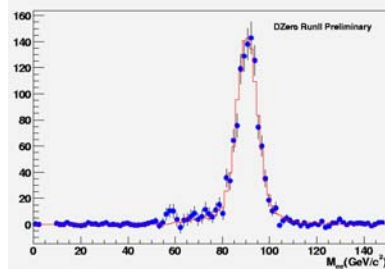
W(eν) candidates: 27370

Z(ee) candidates: 1139

W(μν) candidates: 7352

Z(μμ) candidates: 1585

$$\sigma(Z)\text{Br}(Z \to ee) = 294 \pm 11(N_Z) \pm 8(\text{sys}) \pm 29(\text{lumi})\text{pb}$$

$$\sigma(Z)\text{Br}(Z \to \mu\mu) = 264 \pm 7(\text{stat}) \pm 17(\text{sys}) \pm 26(\text{lumi})\text{pb}$$

$$\sigma(W)\text{Br}(W \to e\nu) = 3054 \pm 100(N_W) \pm 86(\text{sys}) \pm 305(\text{lumi})\text{pb}$$

$$\sigma(W)\text{Br}(W \to \mu\nu) = 3226 \pm 128(\text{stat}) \pm 100(\text{sys}) \pm 323(\text{lumi})\text{pb}$$
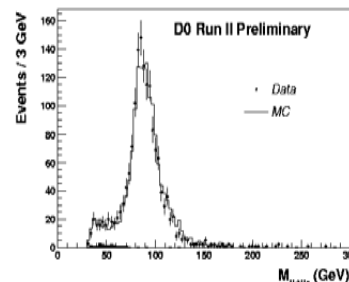
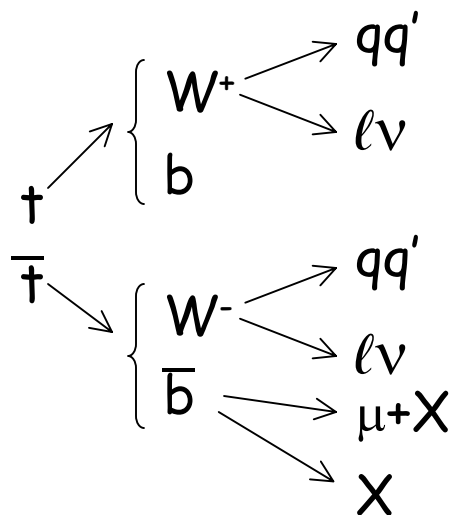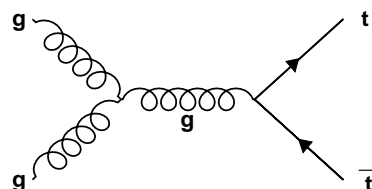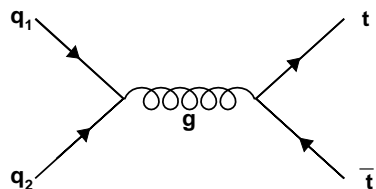**Everything works very well**

W→τν and Z→ττ are on the way…

Top Quark Physics

- ## Production and decays:

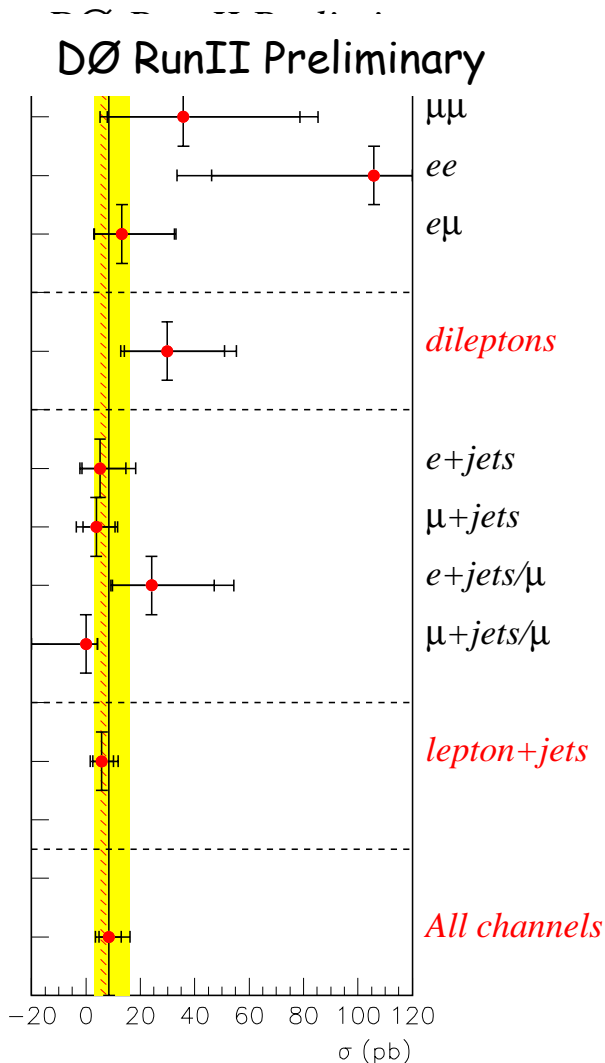produced mostly in pairs

$\sigma(\bar{t}t) \approx 7pb$, ~ 30% higher than at Run I

decay: $Br(t \rightarrow Wb) \approx 100\%$
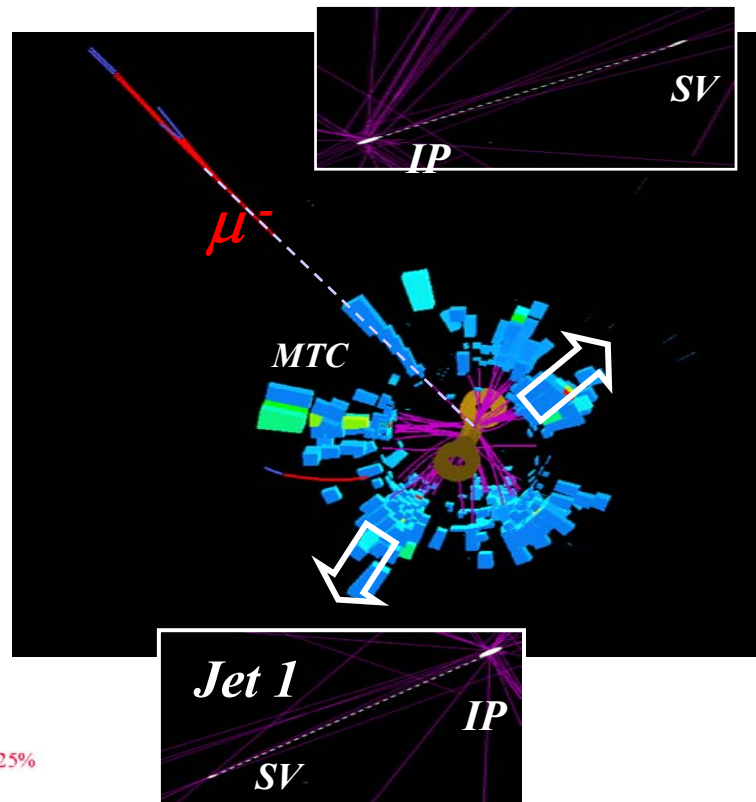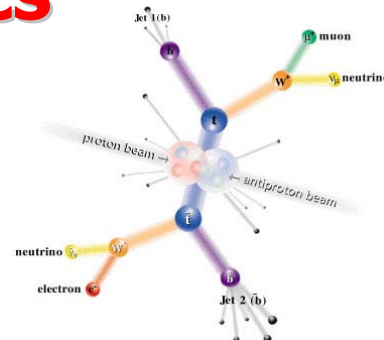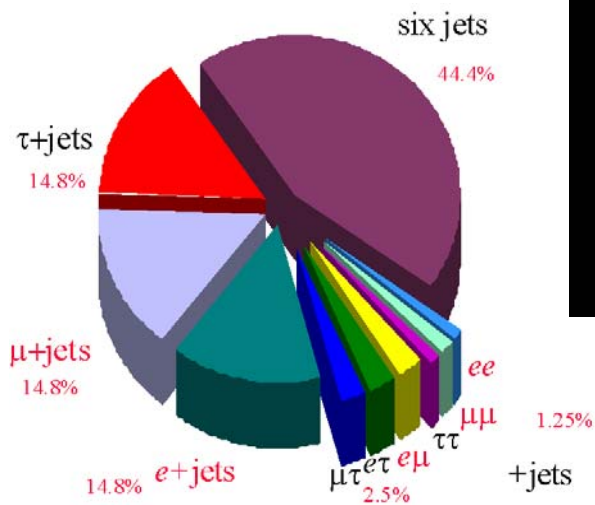
Top Production Cross Section

DØ RunII Preliminary

Channel	Lum (pb^{-1})	Expected Background	Expected Signal for s=7fb^{-1}	Obs.
e+jet	50	2.7+/-0.6	1.8	4
μ+jet	40	2.7+/-1.1	2.4	4
e+jet/μ	50	0.2+/-0.1	0.5	2
μ+jet/μ	40	0.6+/-0.3	0.4	0
$\mu\mu$	43	0.6+/-0.3	0.3	2
eμ	33	0.07+/-0.01	0.5	1
ee	48	1.0+/-0.5	0.3	4
Total	~45	7.9+/-2.9	6.2	17

all channels combined:

$$\sigma(t\bar{t}) = 8.5\,^{+4.5}_{-3.6}\,\text{(stat)}\,^{+6.3}_{-3.5}\,\text{(sys)} \pm 0.8\text{(lumi)}\ \text{pb}$$

theoretical prediction at 1.96 TeV:

$\sigma(t\bar{t}) \approx 6.7$ to 7.5 pb

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New Top Mass Measurement (Run I)

- Top quark mass in lepton + jets channel using a method similar to the one used to measure it in the di-lepton channel

→ **Each event has its <u>own probability distribution</u>**

→ **The probability depends on (almost) <u>all measured quantities</u>**

→ **Each event's contribution <u>depends on how well it is measured</u>**
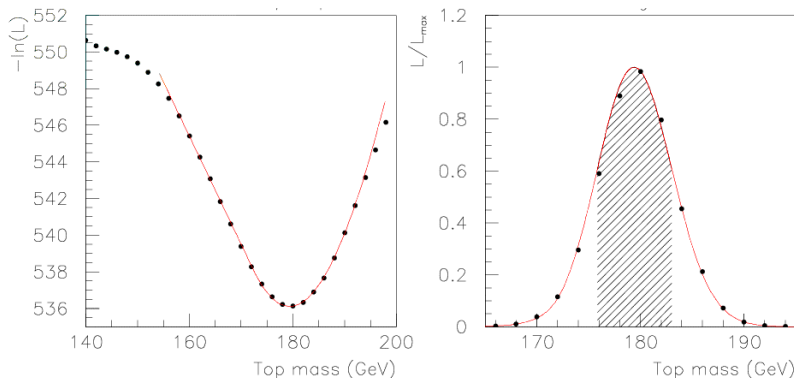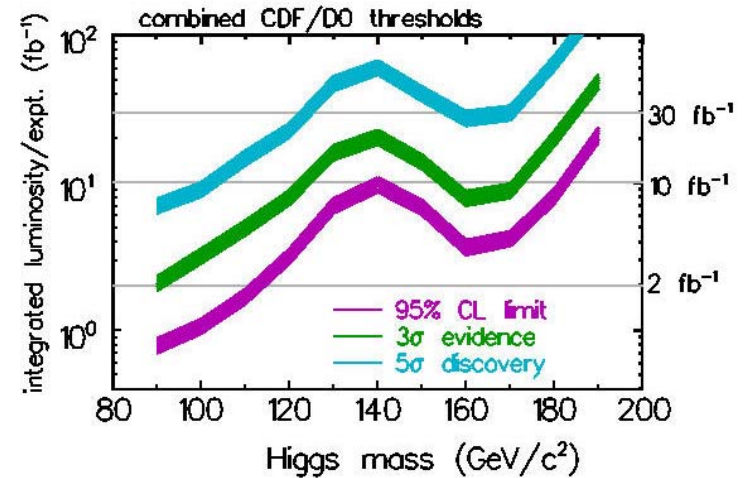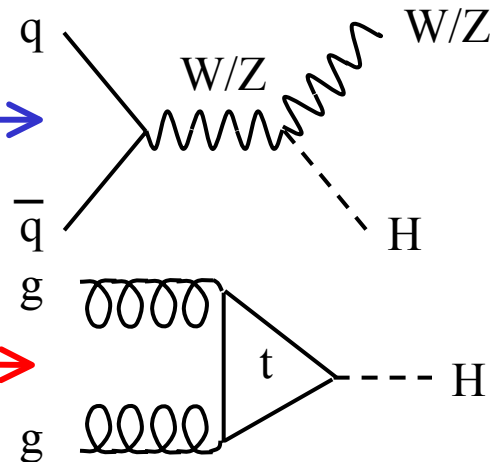

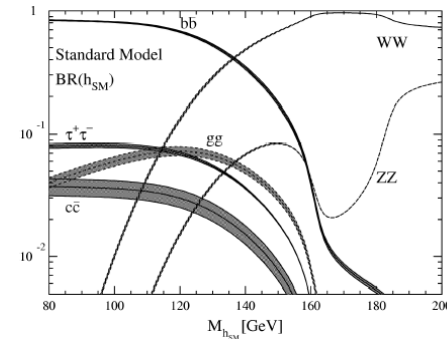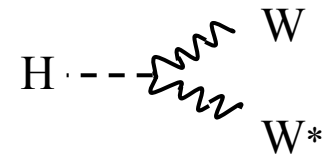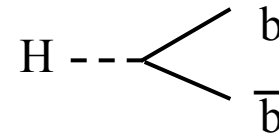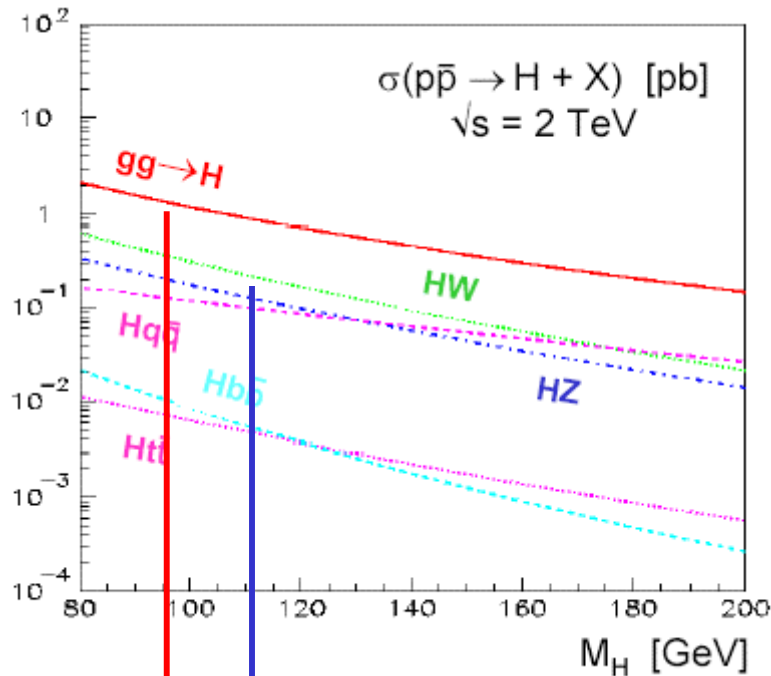$$M_t = 180.1 \pm 3.6 \pm 4.0 \text{ GeV}$$

Was 5.6 GeV in publication

Was 5.5 GeV in publication

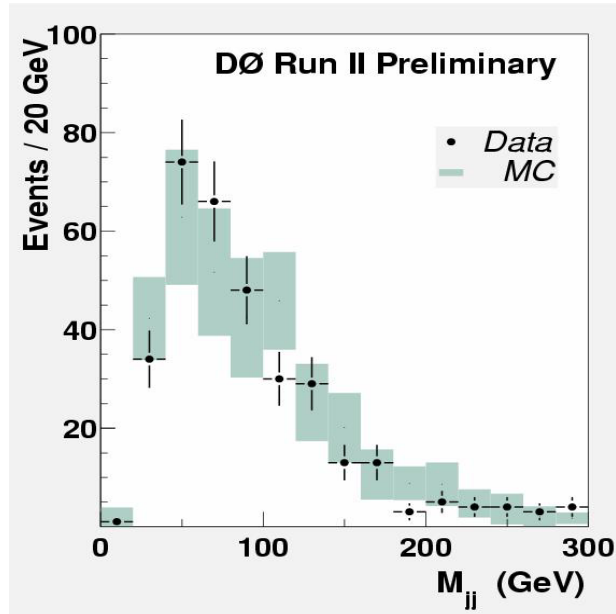Total error (5.4) is similar to combined published Tevatron error (5.1)!

Improvement in error is equivalent to running the Tevatron for two+ more years... (conclusion - be efficient and be smart!)

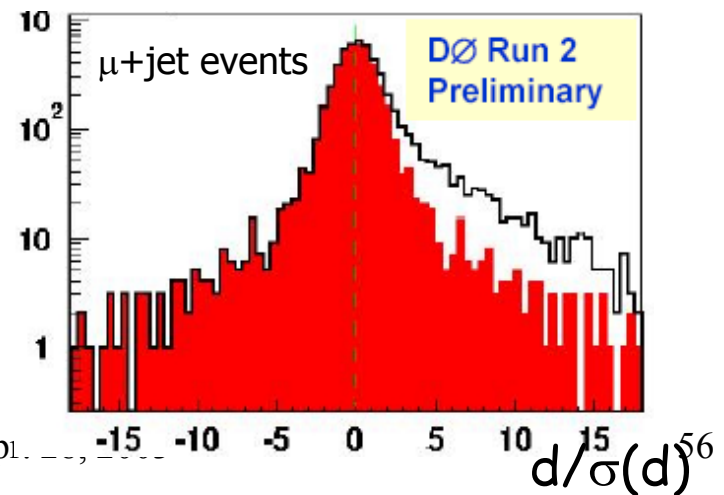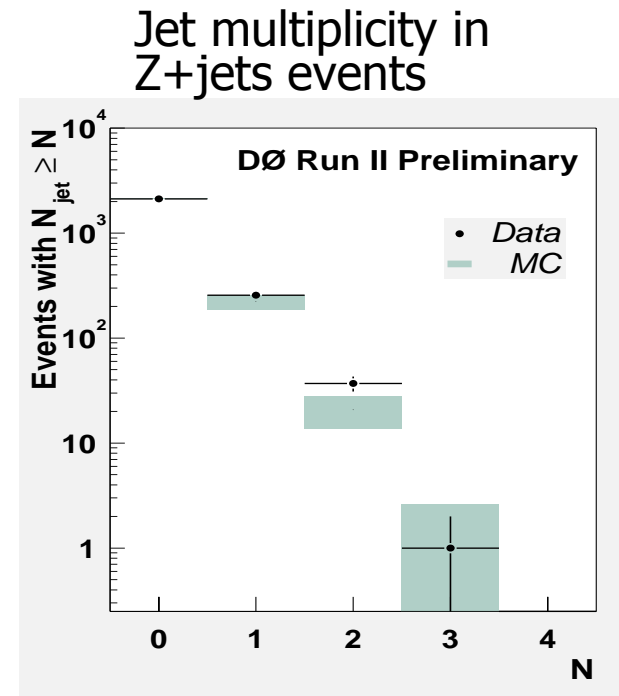# Higgs Searches

Higgs - Low Mass Region

- Understand W/Z + jet production

Jet multiplicity in
Z+jets events

dijet invariant mass in
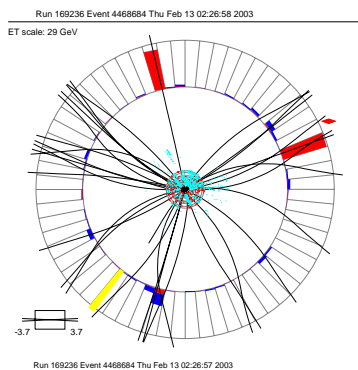W+jets events

- b-tagging

(impact parameter tag)

Higgs - High Mass Region

- $H \rightarrow WW^* \rightarrow \ell^+ \ell^- \nu \bar{\nu}$

  $\rightarrow$ signature: ee, eμ, $\mu\mu$ + $\not{E}_T$

  $\rightarrow$ background: Z/y*, WW, $t\bar{t}$, W/Z+jets, and QCD

Run 169236 Event 4468684 Thu Feb 13 02:26:58 2003
ET scale: 29 GeV

Run 169236 Event 4468684 Thu Feb 13 02:26:57 2003

Bins: 170
Mean: 0.594
Rms: 2.66
Min: 0.09933
Max: 25

mE_t 31.2
phi_t 232 deg

p_T^e = 31.1 GeV
p_T^e = 27.3 GeV
$\not{E}_T$ = 31.2 GeV
m_T = 106.8 GeV
M_{ee} = 36.1 GeV
$\Delta\Phi_{ee}$ = 1.43

ee and eμ channels

DØ Run II Preliminary
$\int L \, dt = 44.5 \, pb^{-1}$

Excluded at 95% CL

LEP excluded (95% CL)

Standard Model
Topcolor
4th Generation Model

Higgs → γγ
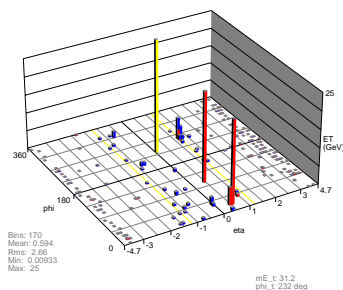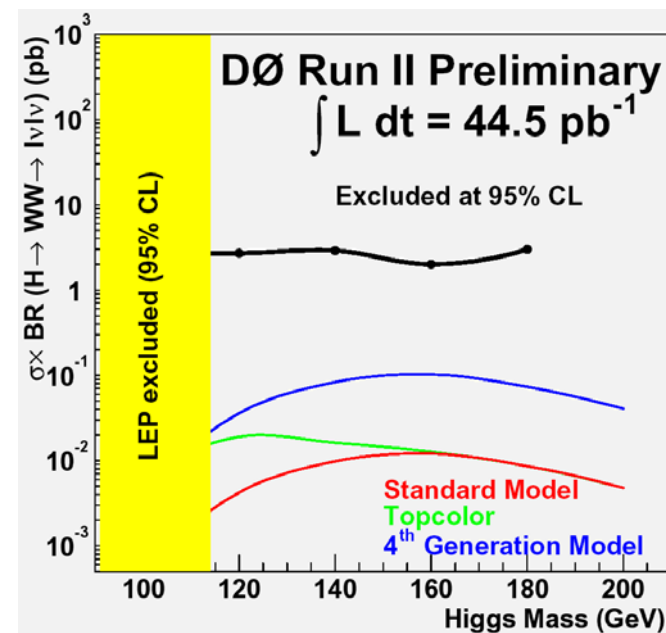
- ## Branching ratio to γγ :

→ in SM, very low: ~ 10^{-3}-10^{-4}

→ enhanced in extensions like

    Fermiphobic, Topcolor Higgs

- ## Search for Topcolor Higgs:

→ $\mathscr{L} \approx$ 52 pb^{-1}

→ 2 isolated EM, E_T > 25 GeV, no track
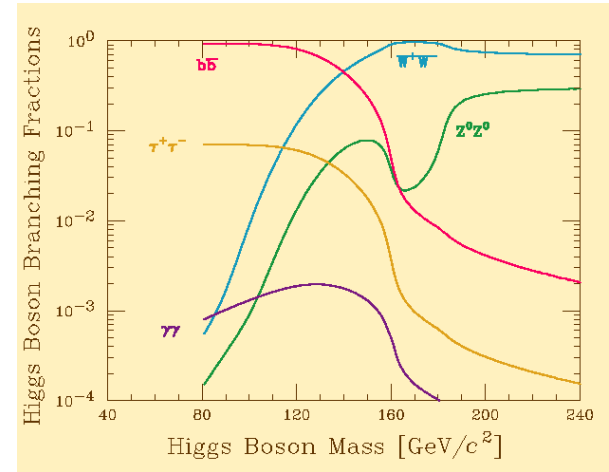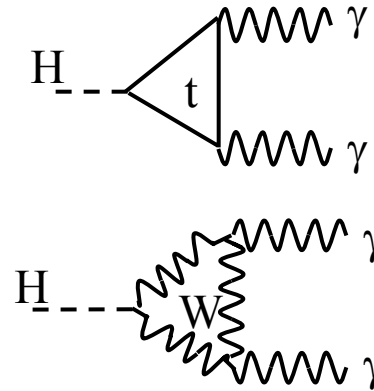matched, mass window cut

→ SM background: Z/γ,
    QCD

approaching region
of interest…

$M_{\gamma\gamma}$ = 202 GeV

Br (Higgs → γγ) = 1

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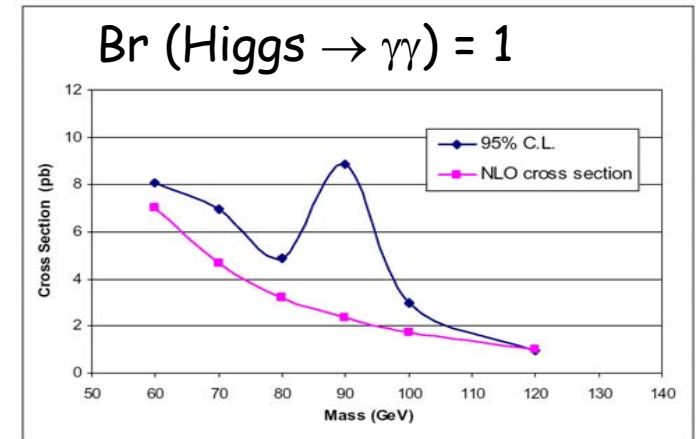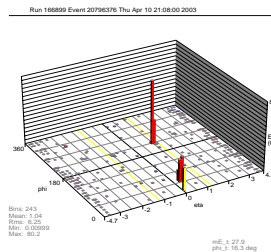
Searches for New Phenomena

- Deviations from SM:

  Supersymmetry:
  - **e, μ + $\not{E}_T$: 3,4-body decays of the stop (Run I)**
  - **Jets + $\not{E}_T$**
  - **Di/Tri-lepton (eeℓ, $\mu\mu$, τ channels, …)**
  - **GMSB: $\gamma\gamma$ + $\not{E}_T$**

  Exotics:
  - **First generation leptoquarks (ee +jets)**
  - **Second generation leptoquarks ($\mu\mu$ +jets)**

  Extra-dimensions:
  - **Di-electrons and Di-photons**
  - **Di-muons**

  …and much more…

Searches for New Phenomena
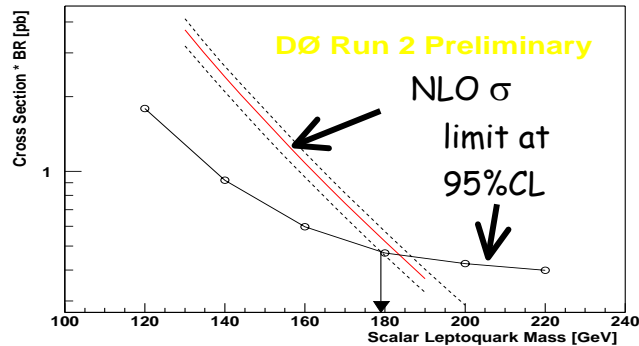
Leptoquarks
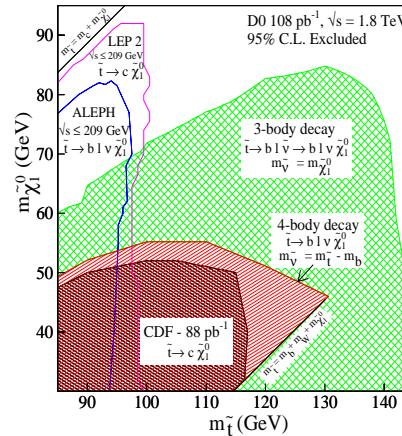
SUSY (sTop)
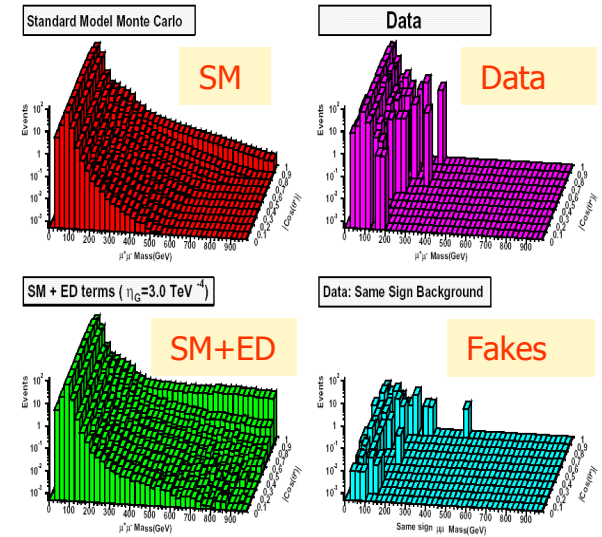
Extra Dimensions

We are closing in on all (many!) Run I limits

Beyond this point everything is possible (uncharted waters)

The level of excitement is growing rapidly

Stay tuned!

Boaz Klima (FNAL)

Brown University - Apr. 28, 2003

Future Prospects

- **Short Term - By this summer's international conferences (LP03 @Fermilab), we expect physics results from Run II with ~ 100 pb^{-1}**

  sample comparable to Run I with improved detectors

  and a higher center of mass energy

- **Long Term -**
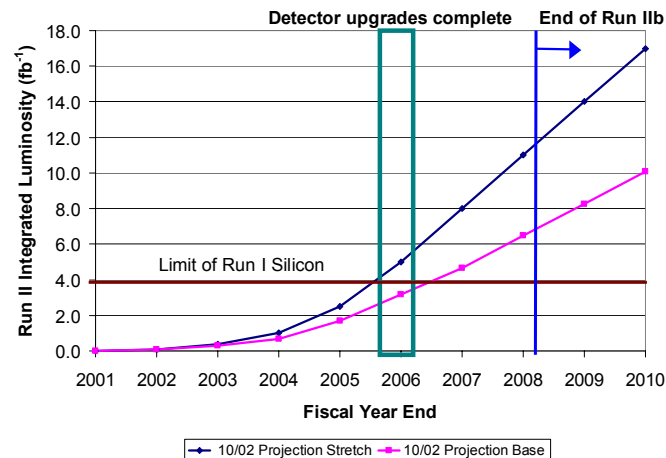
- **To realize the full potential of Run II we must continue to upgrade and invest in the detectors and the accelerator**
- **We will run CDF and DØ until the LHC experiments start to produce competitive physics results**

Run II Physics Program

15 fb^{-1}
- 5σ Higgs signal @ $m_H = 115$ GeV
- 3σ Higgs signal @ $m_H = 115$-135, 150-175 GeV
- Reach ultimate precision for top, W, B physics

10 fb^{-1}
- 3σ Higgs signal @ $m_H = 115$-125, 155-170 GeV
- Exclude Higgs over whole range of 115-180 GeV
- Possible discovery of supersymmetry in a larger fraction of parameter space

5 fb^{-1}
- 3σ Higgs signal @ $m_H = 115$ GeV
- Exclude SM Higgs 115-130, 155-170 GeV
- Exclude much of SUSY Higgs parameter space
- Possible discovery of supersymmetry in a significant fraction of minimal SUSY parameter space (the source of cosmic dark matter?)

2 fb^{-1}
- Measure top mass $\pm$ 3 GeV and W mass $\pm$ 25 MeV
- Directly exclude $m_H = 115$ GeV
- Significant SUSY and SUSY Higgs searches
- Probe extra dimensions at the 2 TeV (10^{-19} m) scale
- B physics: constrain the CKM matrix

300 pb^{-1}
- Improved top mass measurement
- High p_T jets constrain proton structure
- Start to explore B_S mixing and B physics
- SUSY Higgs search @ large $\tan\beta$
- Searches beyond Run I sensitivity

Each gain in luminosity yields a significant increase in reach and lays the foundation for the next steps

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Conclusions

- **In studying high energy collisions between the fundamental constituents of matter, we are not just trying to understand these constituents, we are trying to address big questions about the universe, e.g.**
  - **What is the cosmic dark matter?**
  - **Is the universe filled with energy?**
  - **What is the structure of spacetime?**

- **This Tevatron physics program is based on the detailed understanding of Standard Model particles and forces that we have obtained over the last few decades**
  - **we are guided by theory but also open to the unexpected**

- **The DØ experiment is up and running efficiently, collecting high-quality data, and is already producing many interesting results**

- **A lot more to come!**

- **It's really fun!!**